Teaching High School Science in the Information Age: A Review of Courses and Technology for Inquiry-based Learning

Marcia C. Linn

James D. Slotta

Eric Baumgartner

August 1, 2000

Milken Family Foundation

1250 Fourth St, Fourth Floor

Santa Monica, CA 90401–1353

Table of Contents

1. Introduction

We have reviewed programs designed to improve scientific inquiry in high school classes and have identified promising curricular materials. We discuss the challenges involved, the criteria we have used to identify promising materials, the exemplary programs we have found, and our recommendations.

1.0 The problem and the challenges

We should all be concerned about improving science education so that everyone can use scientific knowledge wisely, not only in educational realms but also in our personal and political lives. Today, far too many people complain that they have forgotten everything they learned in their high school science classes. This problem is underscored all too frequently by accounts of people who have endangered their health or happiness, because they lacked the requisite knowledge to choose among medical treatments, survive in a disaster, or make wise environmental stewardship decisions. Our science education programs can and should provide a better foundation. Instruction based on learning science through personal inquiry is at the heart of the solution.

Inquiry instruction provides students with opportunities to solve engaging scientific problems while articulating, reconsidering, and revising their scientific ideas. In contrast, traditional instruction emphasizes memorizing isolated scientific concepts and vocabulary that students subsequently forget. There is simply not enough time in the curriculum to "cover" every topic and concept in science that students might need in their lives. Instead, we must prepare students to be lifelong science learners who can locate the information they need, analyze the information they encounter in newspapers, magazines, on the Internet, and in social settings, and use scientific information astutely.

Current indicators of success in science education from national and international assessments (e.g., The Third International Mathematics and Science Study, TIMSS) show that American students remember little of what they learn (O'Sullivan, Reese, & Mazzeo, 1997; Schmidt, McKnight, & Raizen, 1997). Many individual remedies for this situation have been proposed, everything from addressing social inequalities by introducing school uniforms to introducing high stakes assessments that "raise the bar" for educational achievement but frequently do not provide support to help students reach these new standards. Alas, quick fixes rarely work in education: the relationships among the many aspects of the educational enterprise are far too intricate and complex. We argue that a much greater impact can be made through a comprehensive response involving curricula, new technologies, professional development, and continuous refinement of instruction.

Over the past decade, new partnerships among science education researchers, classroom teachers, scientists, technologists, and policy makers have developed an approach to science education that creates the firm foundation students need to become lifelong science learners (Barron et al., 1998; Baumgartner & Reiser, 1997; Blumenfeld et al., 1992; Bransford, Brown, & Cocking, 1999; Edelson, Gordin, & Pea, 1999; Kolodner, Crismond, Gray, Holbrook, & Puntembekar, 1998; Linn & Hsi, 2000; Slotta & Linn, 2000). A hallmark of this approach has been the introduction of authentic inquiry opportunities into the science classroom. Inquiry-based instruction is instruction that allows students to engage in the practices of scientists and to construct their own scientific knowledge through investigation rather than memorization. Such instruction often involves the use of scientific tools and methods, and can result in new knowledge that proves useful beyond the bounds of the classroom. Authentic contexts are those in which students feel that the learning is meaningful and relevant to their lives.

When students engage in sustained reasoning about problems that interest them—and when they evaluate their own progress in solving these problems—they begin to practice the lifelong learning skills they will need to deal with scientific questions in the future.

Technological developments in recent years have greatly expanded the opportunities for effective inquiry instruction as well as for lifelong learning. The Internet brings a wealth of information into our homes, classrooms, and communities. This information can be interesting, engaging, timely, and richly varied. It can also be controversial or of questionable value. Many effective inquiry programs prepare students to evaluate this new world of material with a critical eye and to focus on the material most relevant to their needs. Hand-held computing devices and real-time data collection approaches allow citizens to monitor their health, environmental groups to test water, soil, and air in remote locations, and students to gather national and international data on a wide variety of questions (Songer, 1996). To be effective today, science instruction must prepare students to understand and use the new technologies that they will need in the fields they study.

Instruction that fosters personal inquiry offers opportunities as well as challenges. Students will deal with contemporary controversies, go down wrong paths, work in teams to address large problems, reflect on their own understanding, and take more responsibility for evaluating their progress. To engage students in inquiry, educators must change science instruction in many intricate and ultimately interconnected ways. Such redesign typically takes several iterations and often succeeds best when investigated by a partnership with broad expertise. When teachers add inquiry to their curriculum, they need time and support to learn new skills, such as how to coach students who are doing projects, manage teams, deal with novel questions, allocate scarce instructional time, use new instructional technology effectively, and relate new concepts to the ideas that students bring with them into the classroom.

Changing one part of the curriculum inevitably has implications for other activities. When students become better at critiquing scientific arguments, for example, they may start to question activities and materials they previously memorized. When teachers introduce on-line scientific discussion tools students may “chat” rather than analyze scientific questions. Teachers who use inquiry when others are using a traditional approach may feel isolated within their school science department. For this reason, professional development efforts that support innovation in teacher practice must be an integral part of any inquiry program.

Despite the challenges inherent in this demanding new approach to high school science instruction, inquiry-based curricula provide a dramatic opportunity for giving students the lifelong skills they will need to absorb and use scientific concepts wisely. In varying degrees, the programs and materials we reviewed for this report impart the excitement of this new approach to learning and instruction.

Our process for selecting promising programs for review had three phases. First, we selected programs that met the following mandatory requirements:

- Must emphasize authentic inquiry
- Must focus on scientific content
- Must be appropriate for high school students
- Must use technology (new informational and computational tools to support instruction)
- Must be supported by research

Second, we selected programs that met our pedagogical criteria:

- Must be personally relevant to students
- Must encourage cross-disciplinary connections
- Must use technology to enhance understanding
- Must meet diverse student needs
- Must support peer learning

We used these criteria, elaborated below, to select programs we believed were most likely to succeed based on current research in science education. Third, we selected a small set of particularly promising programs to illustrate our recommendations.

1.1 Mandatory screening criteria

We started by conducting a broad review of curricular materials, drawing on a variety of resources to generate a large pool of candidates. To be included in the next stage of review, each of these candidate programs had to meet the following *mandatory screening criteria:*

Provide authentic learning activities. The curricular materials must engage the student in activities that reflect the practice of scientists. Such activities should involve students in constructing knowledge for themselves, testing their own ideas, and increasing their understanding of the world around them.

Provide appropriate science content. The subject matter of the materials must be suitable for use in an integrated science course or a scientific domain traditionally taught in high school. Scientific content, especially in longer curricular units, should relate to national and state science standards. (Materials that did not address science topics directly or that failed to provide a reasonable connection to science standards were not considered for this review).

Provide age appropriate material. The material must be intended for high school-age students in grades 9-12. There are several programs that have produced excellent, technology-supported science curricula for the middle school level, including those of the Project-based Science group at the University of Michigan (Krajcik et al., 1998), the Cognition and Technology group at Vanderbilt University (Barron et al., 1998), and the ThinkerTools group at the University of California, Berkeley (White, 1993). While some of these units could potentially be used in ninth and even tenth grade classrooms, the lack of formal testing in secondary grades along with a focus on subject matter for middle school rule out their inclusion in this review.

Use technology to support teaching and learning. Led most recently by the growth of the Internet and the World Wide Web, technological advances have dramatically changed how people work, play, and learn. The use of technologies such as scientific visualization tools, statistical modeling programs, and dynamic modeling software have become an integral part of scientific practice. This review spotlights programs that are drawing on these resources to support science learning. Rather than focus on the use of technology for technology's sake, we looked for *appropriate* use of technology. By this, we mean the use of technological resources—including personal computers, the Internet, probeware, and less cutting edge forms of technology such as lab kits or even hand tools—that help students to engage in authentic science learning in ways that would not be possible without the technology.

Show empirical benefits to teachers and learners. Each program must be able to cite empirical research that supports the claim that use of the program contributes to effective teaching and learning in the classroom. The benefits of the materials may be shown in terms of student learning gains, student engagement in authentic scientific practice, or teacher professional development. We permitted a wide range of methodologies at this stage; we reviewed studies that ranged from general comparisons to studies of iterative design to case studies. Promising programs that lacked evidence to support claims about the effectiveness of their materials were listed but not considered for exemplary status in this review.

1.2 Pedagogical screening criteria

Once we selected programs using our mandatory criteria, we then evaluated them against pedagogical criteria and reported on their ability to meet these criteria. We developed these pedagogical criteria by synthesizing research on effective instruction (Bransford et al., 1999; Committee on Information Technology Literacy, 1999; Lemke & Coughlin, 1998; Linn & Hsi, 2000). The following pedagogical criteria were employed to determine how a program matched what we see as the core components of a framework for supporting authentic, inquiry-based science instruction:

Connects to personal, relevant, or authentic experiences. Connecting science instruction to personal and authentic science experiences enables students to sort out and integrate their scientific ideas. Students come to science classes with a variety of complex and varied ideas that have emerged from their experience, observation, and prior instruction. For example, students often believe that heat and temperature are the same because the terms are used interchangeably, because their experiences of the two are connected in "feeling" hot or cold, and because the distinction seems esoteric. Instruction that ignores students' ideas has a fleeting impact: unless students have the opportunity to compare their ideas with the normative ones presented in class, they soon return to their much more established views. To prepare students for lifelong learning, the instruction they receive must help them to make connections, test their ideas against the normative ones, and sort out varied perspectives on the topic. Programs are most successful at connecting to personal experience if they can be customized to the needs of individual teachers and schools.

Encourages links to other topics in science. Encouraging links across scientific disciplines enables students to build a more coherent understanding of science and to apply ideas from one course to the next. Students often isolate topics in science class, reporting that chemistry is unrelated to physics or that genetics does not connect to photosynthesis. In contrast, connections among disciplines can help learners to make sense of new information and appreciate the interdependencies of science. Instruction that brings connections to life lets students test new ideas against existing ones and build a more coherent view of science. For example, if students test the idea that heat and temperature are the same against information relating weather conditions to plant growth, they have the opportunity to re-evaluate their ideas and to strengthen their understanding of science. If students understand the difference between heat and temperature, they are prepared to distinguish the rate of heat flow into the soil from the impact of a short period of high temperature on plant health. Programs are most likely to connect to other disciplines if they clearly identify potential links and include inquiry projects that transcend disciplinary boundaries.

Uses technology to enhance understanding. When science programs incorporate technology productively, both students and teachers benefit. The issue here is using the right technology, not just using computers for technology's sake or to help students acquire technical skills. When technology is incorporated into the curriculum, it can expand the number of students who learn and increase the efficiency of instruction. Technology enhances inquiry by enabling students to gather, organize, and display information in new ways. Students benefit from visualizations of complex concepts, animations of interacting systems, and opportunities to interact with experts. Teachers can be more effective when they use technology to support students' activities, freeing them to focus on working with students in depth on individual questions. In addition, science programs that use technology to enhance learning illustrate the role of technology in society and prepare students for the workplace. Technology has been presented as the key to educational reform by progressive educators for many years, dating back to the introduction of moving pictures and radio as promising classroom technologies. The failure of these technologies to reform education has been attributed, among other things, to a didactic instructional model that reflected a lack of understanding about classroom teaching practice and the ways in which teachers adapt technology in their own classrooms (Cuban, 1986). A lesson to be learned from the history of educational reform is that technology for technology's sake does not lead to lasting reform; rather, it is important to understand how technology can be productively integrated into the classroom. Understanding what constitutes productive uses of technology, and how technology may be adapted for the classroom, often depends on research and revision based on field trials. Many programs that use technology effectively to support learning have drawn on a research and development process that incorporates these elements. We emphasize the need to investigate the best uses of technology and not assume that all applications will succeed.

Meets diverse student needs (and has been tested with these populations). Often science programs only succeed with students who learn independently or who already know the material. We sought programs that meet the needs of the broad, diverse student body found in today's schools. The programs we selected invite students to engage in science, support them by offering a variety of ways to learn (such as discussion, projects, reading, designing, debating), and use their views and experience as a springboard to further learning.

Supports peer learning. Students can learn about science from each other. Research shows that students learn from explaining topics to other students as well as from hearing an explanation in the words of a peer (Songer, 1996). Some projects are so large that they need a group of students to succeed. Students who have the opportunity to practice working in a group will be better prepared for lifelong science learning, which depends on the ability to learn from others. Programs that support peer learning typically offer some group and some individual activities and specify how groups work together and how individuals are evaluated when they participate in group work.

Promotes autonomous inquiry. In today's world, it is essential to know how to identify questions that can be answered by scientific inquiry and how to conduct such an inquiry. Science programs can promote independent inquiry by prompting students to reflect on their progress and critique solutions proposed by others. Students who get experience defining scientific questions, researching them, defending their solutions, and measuring their own progress will ultimately have more successful and rewarding lives.

Fosters lifelong learning and revisiting of ideas. To become lifelong learners, students need the inclination to revisit their ideas, the ability to connect new information to existing ideas, curiosity about new scientific topics, and experience carrying out sustained projects. In typical courses, students rarely have the opportunity to develop the abilities necessary for lifelong science learning. Instead, they are asked to follow recipes to conduct experiments and learn vocabulary. No wonder they come to believe that science is irrelevant to their lives! Science programs can foster lifelong learning by meeting all the criteria described above and by ensuring that students carry out complex projects in which they encounter problems and have the chance to refine their ideas.

Using a combination of our mandatory and pedagogical screens, we have identified 27 promising programs, from a pool of over one hundred programs, that can provide students with authentic, technology-supported science learning opportunities. We have grouped these programs into seven functional categories that range from data gathering activities to full, yearlong science curricula. Of these programs, we have selected six that exhibit the characteristics we consider to be critical for improving science instruction. We describe these six programs in somewhat greater detail than the rest.

1.3 Our review and the Milken Family Foundations's "Seven Dimensions of Progress"

We have organized our reviews in terms of contact information, description of the program, effectiveness, professional development, and cost and technical requirements. Our evaluation has been guided by The Milken Family Foundation's framework for progress in educational technology, known as The Seven Dimensions of Progress (Lemke & Coughlin, 1998). These seven questions and their associated indicators have been used as a framework for evaluating the progress of the State of Virginia (SRI, NCREL, Milken, 1998) and a State-by-State Policy Survey Project (Milken, in preparation).

The Seven Dimensions framework offers a very helpful set of questions for assessing the impact and effectiveness of a program. Below, we address each of the seven dimensions, as published by the Milken Family Foundation, and comment upon each in terms of how it is incorporated within our own reviews. Note that, for each dimension, Milken also provides a set of indicators that we will not enumerate here for considerations of space. We will occasionally mention some of these indicators, which can readily be found on Milken's Web site: http://www.mff.org/edtech/.

1. LEARNERS
Are students using technology in ways that deepen their understanding of academic content and advance their knowledge of the world around them?

This dimension is reflected in our selection criteria, which require that technology is being used in a productive way, enabling learners to strengthen basic skills while applying technology in the service of relevant learning goals.

2. LEARNING ENVIRONMENTS

Is the learning environment designed to achieve high academic performance by students?

The focus on academic performance is reflected in our review of the effectiveness of a program (our second main review category). Most importantly, we review program effectiveness in terms of how well it can demonstrate that students have increased their knowledge of relevant subject matter as well as of scientific processes and methods. Our priority is engaging students in such a way that they link their scientific understanding to personal ideas and to problems they consider important.

3. PROFESSIONAL COMPETENCY

Are educators fluent with technology and do they effectively use technology to the learning advantage of students?

Our description category captures the use of technology, but only in part. Another essential aspect of this question is how well prepared the teacher is to implement the project. Even those projects with powerful, well-designed applications of technology are not successful unless they support teachers in learning to use their innovations effectively. We therefore address this dimension in both the description and professional development categories of each review.

4. SYSTEM CAPACITY

Is the entire education system reengineering itself to meet the needs of students in this knowledge-based, global society?

To make progress, a system must be effective in identifying and meeting new needs. Ideally, science projects based on methods of inquiry should contribute to systemic change, as the spirit of inquiry is consistent with reform of conventional instruction. We have addressed this important dimension as much as possible in our reviews, although the projects themselves are generally not intertwined with any specific systemic reform. Thus, we do make some comment about the pedagogical thrust of projects in our reviews, and our selection of projects in itself was guided by this question.

5. COMMUNITY CONNECTIONS

Is the school-community relationship one of trust and respect, and is this translating into beneficial, sustainable partnerships in learning technology?

Many of the projects we review are partnerships among teachers, scientists, educational researchers, technology specialists, and so on. Our own pedagogical framework supposes that such partnerships are the most effective for authoring an authentic curriculum. Within the school community there are many role players who can influence how successful a program will be. While our review of projects cannot comment on these dynamics, we certainly attend to any support that projects provide for engaging an effective community of learners.

6. TECHNOLOGY CAPACITY

Are there adequate technologies, networks, electronic resources and support to reach the education system's learning goals?

While this dimension is less appropriate to the review of any particular inquiry project, it is still very relevant to all projects that have a technological component. Given that the use of technology was a criterion in our selection of projects, we are in certain alignment with the spirit of this question and all of its indicators. To the extent that school communities embrace and support technology, all of the projects that we review will be more likely to succeed.

7. ACCOUNTABILITY

Is there agreement on what success with technology looks like? Are there measures in place to track progress and report results?

Many of the indicators that The Milken Family Foundation provides for addressing this dimension are inherent in the school communities themselves – and are, therefore, beyond the scope of our review. Still, if projects like those we are reviewing are to thrive, they must have educational goals and measures that are congruent with those of the school communities in which they are implemented. Further, the school systems must recognize the value of innovative attempts to achieve overarching educational goals. For example, a project that seeks to use new technology to give students lifelong learning skills can thrive in a school system that embraces this outcome as one of its priorities. Without such institutional commitment and support, the project might be deemed irrelevant or unnecessary.

1.4 The Florida State Standards, our evaluation criteria, and the "Seven Dimensions of Progress"

The State of Florida has prepared a detailed set of standards that are designed to help parents understand educational goals and to hold schools and teachers accountable for student achievement. The state's Web site describes the role of standards as follows:

> *Simply, standards are what we expect students to know at certain stages of their school career. The Sunshine State Standards are a collection of concepts we expect students to know and understand as they progress through school. The Standards don't tell teachers how or what to teach. Nor are they lesson plans. They are only guidelines that tell teachers and parents what students are expected to know. Standards will help teachers provide the best education possible to Florida's students.*

Sunshine State Standards Web site:
http://www.firn.edu/doe/curric/prek12/over.htm

Below, we discuss how the Florida State Standards relate to our review criteria and to the Milken Family Foundation framework.

Standards Relating to Science Content

The Florida State Standards specify science content and process standards quite thoroughly for all grade levels. High school standards and benchmarks are grouped together, and the content is divided into categories: the nature of matter; energy; force and motion; earth processes; earth and space, processes of life, how living things interact with their environment; and the nature of science. These divisions are consistent with many other state frameworks, as well as with the national standards advocated by the National Research Council (NRC, 1996). Each standard is illustrated by a set of very explicit benchmarks. For example, there are two standards in the category of Earth and Space:

- The student understands the interaction and organization of the solar system and the universe and how this affects life on earth
- The student recognizes the vastness of the universe and the earth's place in it.

The latter standard has seven benchmarks that address content knowledge (e.g., benchmark #3: "knows astronomical distance and time") and connections to other disciplines, technology, and the scientific process (e.g., benchmark #7: "knows that mathematical models and computer simulations are used in studying evidence from many sources to form a scientific account of the universe").

Standards Relating to the Nature of Science

Perhaps the most important category of the Florida State Standards is that of the "Nature of Science," which must be addressed in conjunction with other science courses, since there is no way to effectively teach this category separately from a disciplinary context. Three standards are enumerated in this category, and each of them is a vital and highly respectable aim for science instruction.

The first standard states that "The student uses the scientific processes and habits of mind to solve problems." This standard is accompanied by seven very thoughtful benchmarks. We provide three of these benchmarks, to illustrate the importance of inquiry activities within the science curriculum:

- knows that investigations are conducted to explore new phenomena, to check on previous results, to test how well a theory predicts, and to compare different theories.
- knows that from time to time, major shifts occur in the scientific view of how the world works, but that more often, the changes that take place in the body of scientific knowledge are small modifications of prior knowledge.
- understands that no matter how well one theory fits observations, a new theory might fit them as well or better, or might fit a wider range of observations, because in science, the testing, revising, and occasional discarding of theories, new and old, never ends and leads to an increasingly better understanding of how things work in the world, but not to absolute truth.

These benchmarks can best be achieved when students engage in testing hypotheses or comparing arguments. Thus, the inquiry-based projects we have reviewed are quite relevant to the achievement of this and other process standards.

The second standard in this category connects well with the ideas of inquiry, especially in conditions of guided discovery: "The student understands that most natural events occur in comprehensible, consistent patterns." Two general benchmarks are provided for this standard:

- knows that scientists assume that the universe is a vast system in which basic rules exist that may range from very simple to extremely complex, but that scientists operate on the belief that the rules can be discovered by careful, systemic study.
- knows that scientists control conditions in order to obtain evidence, but, when that is not possible for practical or ethical reasons, they try to observe a wide range of natural occurrences to discern patterns.

The final Nature of Science standard, "The student understands that science, technology, and society are interwoven and interdependent," resonates with the Milken framework for progress. According to the Seven Dimensions of Progress, students should understand this aspect of science, perhaps, above all others. It is this kind of goal within our school science curriculum that will enable students to become lifelong science learners and to perceive the value of science and technology in society. Six benchmarks are provided for this standard, including the following:

- knows that scientists can bring information, insights, and analytical skills to matters of public concern and help people understand the possible causes and effects of events.
- knows that the value of a technology may differ for different people and at different times.
- knows that scientific knowledge is used by those who engage in design and technology to solve practical problems, taking human values and limitations into account.

The Milken Family Foundation has provided an evaluation framework that underscores the importance of these benchmarks, particularly those relating to the scientific process. Curricula that emphasize authentic science content and inquiry-style activities will contribute to the achievement of these important standards.

2. Program descriptions

Field descriptors

To describe the nature, promise, and effectiveness of each program, we have organized our descriptions in terms of contact information, description, effectiveness, professional development, and cost and technical requirements.

Contact information. For readers who wish to learn more about a program, we provide a Web site URL, information about obtaining the program, and e-mail and telephone contact information where available.

Description. A general overview of the program that includes the subject matter addressed, learning objectives, targeted student population, and connections to national or state standards (where documented by the program developers). We also include information about the instructional, assessment, and management strategies employed.

Effectiveness. A critical analysis of research about a program as well as a discussion of how the program's learning and pedagogical approaches align with our framework.

Professional Development. A description of what it takes to prepare teachers to use the program and what the program provides, including skills for using new technologies, instructional strategies, organizational strategies, support requirements, and kinds of support offered (e.g. in-services, summer workshops, phone support, etc.)

Costs and technical requirements. Implementation costs, including technological requirements, resources needed, and expectations about the technical skills of students and teachers.

2.1 Comprehensive curricula

This review category includes programs that provide all the written materials, technology, and supplies needed to support student activities and to involve students actively in a complete, full-length science course.

Traditional science curricula have long faced difficulties in engaging students in authentic inquiry. Textbook-based courses, in particular, have not fostered questioning from students (Pizzini, Shepardson, & Abell, 1992), due in part to the nature of the textbook, which lends itself to predefined activities for which there are expected "right" answers. In contrast, the programs included in this section use a broad range of approaches that support authentic inquiry, including workbooks, activity kits, scientific visualization and dynamic modeling software, and material available on the World Wide Web.

The programs described here offer course content for chemistry (ALICE), life and earth sciences (Fluid Earth, Living Ocean), physics (CPU), and integrated science (Science and Sustainability). Programs like Virtual High School extend the traditional science curriculum, providing opportunities for teachers and students to participate in courses not offered at their own school.

Comprehensive curricula, by their very nature, have a greater responsibility to address national and state science standards than do shorter units, which are often supplemental. Each of the programs described in this section addresses the standards directly, and also provides assessment guidelines to help teachers evaluate student learning. Programs are reviewed in alphabetical order.

Active Learning In Chemistry Education (ALICE)

Contact information

Web site: http://chem.lapeer.org/Alice/Alice.html

Developer: A. J. Girondi, Ph.D., 505 Latshmere Dr., Harrisburg, PA 17109.

E-mail: alicechem@geocities.com

Description

The Active Learning In Chemistry Education (ALICE) materials are designed to be used as a first year high school chemistry course. The materials prepare students for a second year of high school chemistry or a science-related career. ALICE can be downloaded and printed for students, thus giving learners their own copy of the text. The ALICE philosophy calls for the teacher to interact with students through coaching rather than lecturing. The pedagogical philosophy of ALICE is to minimize lectures and encourage activities with standard laboratory equipment so students can be more active learners.

Using ALICE, students read materials, write answers directly in their copy of the curriculum, solve problems, and conduct laboratory activities with equipment found in typical laboratories. Teachers using ALICE can replace lectures with opportunities for students to work in groups, answering questions and solving problems.

The 29-chapter curriculum includes topics on theory, such as atomic theory and structure. There is a strong emphasis on quantitative problem solving. Learning outcomes are listed at the end of each of the chapters. The teacher designs the assessment.

Typical ALICE students include those who do well in rigorous science and math classes and who may wish to pursue a career in a science-related field. A good background in first-year algebra is required, and second-year algebra is recommended. ALICE is not recommended for use at the middle school level.

Effectiveness

The developer reports, "The program has been revised many times based on input from students and colleagues. I used ALICE in my first-year classes for more than six years. I believe that it can be a tremendous help to the beginning chemistry teacher, and can provide a refreshing change of pace for veterans. The vast majority of my students have responded very favorably to the learning style and overall experience that this unique approach provides."

Students in the developer's second-year chemistry classes were a mix of those who had used ALICE and those who had taken a traditional chemistry class. The developer noted “no significant difference in the performance of the ALICE group and the traditional group on the standard assessments,” and concluded, “I considered this to be a very positive finding, since ALICE required much less lecture and put students into a much more active role.”

ALICE is currently being used in many states. The developers are encouraged to undertake research on its effectiveness.

Professional Development and Support

ALICE is designed to be used by both experienced and novice teachers. The developer does not believe that professional development activities to help teachers use ALICE are needed and has not introduced any.

Costs and Technical Requirements

The developer is making ALICE available to non-profit public or private schools free of charge. Home-schoolers may find ALICE to be useful; however, very few of the laboratory activities included are appropriate for the home. The materials are protected by a registered U.S. copyright. Written permission must be obtained in order to participate.

The cost of the program should be about the same as that of a traditional program. Traditional courses use textbooks that are typically used for about five to seven years. The ALICE program requires that the materials be duplicated for students who assemble them into a notebook, which they take with them at the end of the course. ALICE requires little or no special equipment, although many of the activities can be enhanced through the use of modern laboratory technology.

Conceptual Physics

Contact information

Website: http://www.cpsurf.com/

Description

This program is a full semester curriculum for high school physics, and contains materials that were written with special attention to the conceptual level of discussion. The course uses language that is easy to understand, and ample cartoon illustrations reveal the profound simplicity that underlies much of the physics theory. The curriculum includes a set of activities as well as the companion textbook, *Conceptual Physics*, by Paul Hewitt, which has been a popular companion text for more than a decade. All activities within the curriculum are designed according to a three-stage learning cycle: Exploration, Concept Development, and Application. In the first stage, students carry out laboratory activities and computer simulations designed to engage their interest. In the second stage, students develop their conceptual understanding through readings, assignments, lectures, and class discussions. In the third stage, students apply their understanding through laboratory work, computational problems, and discussion of questions that encourage critical thinking. The program includes a teacher's guide, a teacher's resource package, test software, and an overhead transparency package.

The semester-long curriculum divides physics into six units: mechanics, matter, energy (heat, sound, and light), electricity and magnetism, and atomic and nuclear physics. The laboratory manual provides experimental activities designed to help students identify relationships between important physical quantities. These exercises precede the textbook and lecture material. For example, in one laboratory exercise, students experiment with a spring balance in order to explore the relationships between mass, acceleration, and spring forces. The students are on ice skates while they perform these experiments, and are pushed or pulled by classmates! Student worksheets help to expand on these experiments by providing helpful analogies and problem-solving exercises. Finally, a set of class discussion questions helps students and teachers alike as they reflect on the activities, text, and conceptual problems.

Effectiveness

While the publisher has not provided data about student learning, Hewitt's companion textbook has long been a favorite with teachers. In addition, many researchers in education and psychology have utilized Hewitt's text material in their studies of physics conceptualizations. For example, Dr. Michelene Chi has employed materials from Hewitt's treatment of electricity in her studies of physics learning (Slotta, Chi, & Joram, 1995). Chi and other researchers have acknowledged the effectiveness of Hewitt's conceptual level of treatment. By careful writing, rich examples, and helpful illustrations and analogies, he has made physics concepts more accessible to lay readers and physics students alike.

Professional Development and Support

Several kinds of supports are available for teachers who adopt this project as their physics curriculum. Most importantly, a teacher's guide—an annotated version of the student text—contains teaching tips and helpful annotations. The guide describes relevant technological products, provides discussion questions, and gives answer keys to student problems. A Teacher's Resource Package includes the teacher's guide, lecture notes, test materials, and a laboratory manual. In addition, an overhead transparency package and test generating software are also available, as are a companion Web site and Internet activities for students.

Costs and Technical Requirements

Primary materials available include the TestWorks test generator CD-ROM package ($99.00), student textbooks ($48.84), teachers' edition texts ($38.66), overhead transparency packages ($143.52) and a teacher resource package ($76.44).

Other student materials available include a laboratory manual, a concept development practice book, and problem-solving exercises. Contact the vendor for more information. The Teacher's Resource Package components are available separately.

Comprehensive Conceptual Curriculum for Physics (C3P)

Contact information

Website: http://phys.udallas.edu/

Address: C3P Project Office, Department of Physics, University of Dallas, 1845 East Northgate, Irving, TX 75062-4799; Phone: 800/526-8472; Fax: 214/721-5052

Principal Investigator: Richard P. Olenick, Professor of Physics, University of Dallas. E-mail: olenick@phys.udallas.edu

Description

The Comprehensive Conceptual Curriculum for Physics (C3P) is a high school curriculum that integrates video-based, inquiry-based, and lab-oriented materials to promote exploration of such topics as Habits of the Mind; Matter, Space and Time; Kinematics, Forces, and Newton's Laws; Energy and Conservation; and Waves, Electricity and Magnetism. The mission of the C3P project is "to produce a comprehensive conceptually based physics curriculum for all high schools, usable by all teachers, and effective with all students."

C3P is based on current research examining students' ideas about physics. The goal of C3P is to improve the quality of physics instruction in the nation's high schools by helping teachers rely less on lectures and more on inquiry, learning cycles, hands-on activities, interactive strategies, and conceptual understanding. Teachers are viewed as continuous learners who explore their own understanding of their discipline, their students, and their teaching practices. C3P encourages teachers to investigate their students' understanding of key concepts in physics and to apply research results to enhance teaching effectiveness. The developers want teachers to explicitly recognize students' prior experiences and knowledge as reflected in their ideas when they enter class. Instruction involves providing concrete experiences with phenomena to make the vocabulary of physics understandable.

The materials guide students systematically from concrete experiences and descriptive expressions to quantitative reasoning. C3P takes advantage of the short-term motivational power of relevant experiences by consistently connecting the physics learned to everyday applications, to history, and to other disciplines. This approach reduces the number of topics in the curriculum so that it can foster conceptual understanding at greater depth. This means that some topics listed in standards and frameworks will inevitably be left out, illustrating the difficult, if familiar, trade-off between depth and breadth in curriculum coverage. The materials incorporate assessment procedures and instruments congruent with the curriculum to measure student skills, knowledge, understanding, and reasoning.

C3P addresses the Science Content Standards in the National Science Education Standards developed by the National Research Council. In supporting those standards, the curriculum emphasizes physics as a method of inquiry, the unifying concepts and processes of physics, and the history and nature of physics. According to the developers, C3P helps students “to know how scientists know” and to acquire the skills necessary for inquiring independently about the natural world. Content goals are integrated into specific topics, units, and sequenced activities that help students make sense of fundamental ideas in physics. Rich in strategies and materials, the C3P curriculum is flexible enough to accommodate a variety of teachers and students.

The curriculum materials are also incorporated as a multimedia CD-ROM that contains learning objectives; daily lesson plans; learning cycle activities for explorations, concept development, and applications; and an assessment component. Also available are video clips, microcomputer-based lab activities, simulation software, teacher instructional development software, and tracking software to follow students’ progress as they use the CD-ROM interactively.

Effectiveness

A trial and refinement model is being developed to assess the effectiveness of C3P. More than 100 teachers with a variety of backgrounds in diverse environments will pilot test the materials. These tests, along with reviewer’s recommendations, will guide the revision and refinement of the curriculum.

While no results are yet available, C3P is based on research and experience. The curriculum incorporates instructional materials and strategies that have been shown to improve the teaching of physics in high school, to increase students’ motivation for studying physics, and to improve students’ understanding of essential concepts.

Professional Development and Support

Peer-led workshops are conducted by 75 teachers throughout the nation. In these workshops, participating teachers develop a framework of year-long goals for their students, deepen their own understanding of physics concepts, and explore and adapt teaching strategies that help students improve their understanding of concepts and processes. In addition, the Web site offers contact information.

Costs and Technical Requirements

C3P 2000 is available for $150. New features include improved lesson plans; more video clips and a video resource list; easier navigation; Web links; new activities; World-in-Motion for PC and VideoGraph for Mac video analysis software; and Autoinstall. The CD-ROM contains the curriculum; all the resource materials (approximately 11 binders); lesson plans; learning cycles; video clips; assessment items; and an historical timeline of physics and world events.

The following C3P files in Adobe Acrobat are available at its Web site: Concept Maps, Correlation to National Standards, Summary of Several Standards Projects, Historical Timeline, and the entire C3P CD-ROM.

Constructing Physics Understanding (CPU)

Contact information

Web site: http://cpuproject.sdsu.edu/

CPU Project Staff: Fred Goldberg, Patricia Heller, Sharon Bendall, Jim Minstrell, Robert Morse, Paul Hickman, Jennifer Hickman, Shannel Honoré, Andy Johnson, Laura McCullough, Valerie Otero, Pat Walker, Mike McKean, and Brook Smith.

Description

Constructing Physics Understanding (CPU) is a National Science Foundation-funded project designed to encourage students to take primary responsibility for developing a valid and robust knowledge of physics. The CPU project has created laboratory and computer-based materials to help secondary school physics and physical science students in high school classes, prospective teachers in university courses, and practicing teachers in workshops.

The pedagogy is based on cycles that involve (a) eliciting students' ideas, (b) guiding students to modify or discard their old ideas and/or develop new ones in a movement towards target ideas, and (c) applying the target ideas to new situations.

The CPU project has developed seven units: Light and Color; Motion and Force; Waves and Sound; Static Electricity and Magnetism; Current Electricity;

Underpinnings; and Nature of Matter. Students work through these units on the computer. This use of computer technology provides simulations of complex systems that are not available in a pencil and paper format.

CPU pedagogy and materials are closely aligned with the NRC National Science Education Standards (NSES) and the AAAS Benchmarks for Science Literacy (AAAS, 1993; NRC, 1996). In addition to content and pedagogy standards, the project is in alignment with the standards in areas such as the nature of science, science as a human endeavor, and the nature of scientific inquiry.

Effectiveness

The CPU project builds on previous work incorporating computer technology and innovative pedagogical methods to create an inquiry environment. Results are reported in Otero, Johnson and Goldberg (in press).

Professional Development and Support

CPU offers content and implementation workshops to K-12 teachers throughout the United States. The workshops use the pedagogy, software, and units developed by the CPU project. Content workshops serve elementary teachers and some middle school teachers who want to develop a better understanding of various physics concepts. Implementation workshops present the CPU pedagogy, materials, and software for secondary school classrooms.

Workshops are offered by 25 trained CPU Leadership Teams. Each team consists of three members, including at least one university faculty member and one high school physics teacher. To prepare for the workshops, these teams attended two, 15-day CPU training sessions in San Diego, trial tested materials in their own classrooms, and attended three-day follow-up meetings in 1998 and 1999.

Leadership Teams are committed to giving three workshops, each lasting the equivalent of 15 days, with an anticipated enrollment of 20 teachers in each workshop. CPU provides partial support for the workshops. Many teams have arranged for stipends, academic credit, professional growth points, or small equipment kits for workshop participants.

Costs and Technical Requirements

CPU units can be printed out for use in classrooms not equipped with computers or equipped with only one demonstration computer and an LCD panel. Originally developed using the OpenDoc Framework, the CPU software is currently being reprogrammed in Java for use with all types of computers.

Fluid Earth, Living Ocean

Contact information

Web site: http://www.hawaii.edu/crdg/programs/science/felo/

Developers: Curriculum Research & Development Group (CRDG), University of Hawaii, 1776 University Avenue, Honolulu, HI 96822. Phone: 800/799-8111; Fax: 808/956-9486; Email: crdg@hawaii.edu.

Description

Fluid Earth, Living Ocean (FELO) consists of two semester-long multidisciplinary courses built around marine science. The program emphasizes lab- and field-based investigations as well as connections to current technological applications and relevant environmental issues. Each course consists of several units that may be used in any order. Units in Fluid Earth address earth and ocean basins, waves and beaches, physical oceanography, chemical oceanography, and transportation, while Living Ocean units focus on fish, invertebrates, plants, and ecology.

Each unit is comprised of a series of activities that have been designed to build on one another when used in sequence. Student activities are focused on investigation and often involve hands-on use of materials. For example, in one activity, students design and build a wave tank to observe wave behavior. In another activity, students make a fish print, and then evaluate the print as a technique for documenting fish attributes.

Fluid Earth, Living Ocean's activity-based approach to learning science relies on technology to succeed, but takes a different approach than do many of the other programs in this review; computer technology is not a part of these units. Rather, the technology takes the form of tools and instruments that students use as they pursue lab and field work. Students also explore technology as a subject domain, focusing on the use of technology in the marine environment, including ocean-mapping technologies and seabed mining. FELO emphasizes how scientific concepts can be applied to design and engineering settings. This approach aligns the curriculum well with national science standards for science and design, and CRDG provides reports for aligning the curriculum with both the national science standards and the AAAS benchmarks.

Effectiveness

There have been no direct studies to document the effectiveness of FELO; however, the program developers point to two recommendations that suggest their materials are appropriate for authentic science learning.

- In 1994, the ten Regional Educational Laboratories, a network of non-profit organizations funded by the Department of Education to support educational improvement at local, state, and national levels, conducted a search and review of curricula that incorporated promising practices in math and science education. Fluid Earth, Living Ocean, along with two other CDRG projects, was among the 67 programs selected. The success of multiple curricular programs from CDRG suggests that the group's approach to curricular design is consistent with the review criteria, which focused on programs that took innovative approaches to learning and related to the emerging science standards.
- FELO has also been named an exemplary program by the National Science Teacher's Association's Search for Excellence in Science Education project.

Professional Development

CDRG runs ten-day summer workshops in Hawaii, and will run local workshops if there is interest. These workshops allow teachers to engage in activities from the perspective of students, while learning about the program's marine science content and its pedagogical approach. Participation in a teacher's institute is mandatory for teachers who wish to use FELO.

Cost

A teacher's kit, priced at $350, includes workbook masters, a teacher's manual, one student textbook, and a set of related texts on fishing in the Pacific. Additional student textbooks cost $26. Teachers who participate in teacher institutes, which normally cost about $800, receive a teacher's kit free of charge.

Minds-On Physics

Contact information

Web site: http://www-perg.phast.umass.edu/outreach/MindsOnPhysics/default.html

Publishers: Kendall/Hunt Publishing Company, Orders, 4050 Westmark Drive, P. O. Box 1840, Dubuque IA 52004. Publisher Web site: http://www.kendallhunt.com/

Phone: 800/770-3544

Fax: 800/772-9165

Description

Minds-On Physics (MOP) is an activity-based, full year curriculum for high school physics. Written by the Physics Education Research Group (PERG) at the University of Massachusetts, MOP materials take into account research about the teaching and learning of physics as well as experience in physics teaching. The goal of MOP is to improve learning and to sustain students' interest by providing them with an active learning environment and cooperative group work.

MOP consists of five volumes of physics activities for students and four Teacher's Guides. The three-volume mechanics portion of the curriculum includes approximately 100 activities. Another 50 activities help students explore electricity, magnetism, gravity, circular and rotational motion, relative motion, and projectile motion. An additional volume of activities—addressing concepts in fluids, heat, thermodynamics, entropy, oscillations, and waves—and two more Teacher's Guides are to be published by summer, 2000.

MOP activities are designed to take students' ideas about content into account. Through careful construction and sequencing, the activities encourage students to explore their understanding of physics-like concepts, to refine their understanding of formal physics concepts, and to investigate connections among related concepts. Activities require students to interact with teachers and peers, while reflecting on past experiences and previous activities. The curriculum frequently revisits main concepts (e.g., Newton's Laws of motion) to help students integrate those principals.

Each student activity has four stages:

- Expected Outcome, which introduces the concepts and principles that are involved in the activity
- Prior Experience, which helps students prepare for the activity by making sure they have important background information
- Main Activity, which contains activities and problems designed to help students reflect on the material
- Reflection, which asks students to look back at their answers and try to find patterns or generalizations.

Each activity can be completed in a one-hour class period. Some activities also involve hands-on manipulation of data, including substantial lab reports. Each activity is accompanied by a short (one-page) entry in a student reader and provides assessment items, instructional materials for teachers, and supplemental discussions.

Intended to be an excellent preparation for college-level science, MOP is well matched with the National Research Council's National Science Education Standards.

Effectiveness

The Minds-On Physics materials have been studied extensively by a professor of physics education at the University of Massachusetts and by a team of graduate students there. The team studied classroom trials of the materials, using videotaped recordings, questionnaires, and interviews to explore the effects of the instructional materials. Their studies found that students acquired expert-like problem-solving skills and were more aware and confident of their physics knowledge (Gerace, Dufresne, Leonard, & Mestre, 1999). Teachers learned some new conceptual material, became more aware of student conceptualizations, and gained awareness of some educational research results.

Professional Development and Support

This full curriculum, developed with National Science Foundation funding, includes a substantial set of teacher materials, such as a two-volume teacher's guide, transparency sets, and assessment materials. While supplements for teachers are included in these materials, and the project does support a substantial Web resource for teachers, MOP does not offer professional development programs. Gerace et al. (1999) observed, "Most teachers did not change their instructional practices very much during their involvement with the project. However, there was change, and it was slow, with larger changes associated with longer involvement with the developers. This suggests that teachers need intensive and protracted support in order to change their instructional approaches." Thus, it appears that adopting MOP is a significant undertaking for most teachers.

Costs and Technical Requirements

No substantial technical requirements are necessary in order to implement this curriculum. The cost of the materials, per unit, are $15.99 per text and $34.99 for teachers' guides.

PRIME Science

Contact information

Web site: http:// www.teleport.com/~cgrether/resource/curriculum/prime1.html or http://www.vismt.org/curriculum/progs/olddocs/prisci2.html

Publisher: Kendall/Hunt Publishing Co., 4050 Westmark Dr., P.O. Box 1840, Dubuque, IA 52004.

Phone: 800/228-0810

Description

PRIME Science is an American adaptation of "Salter's Science"—a well-tested British multidisciplinary science program for middle grades. The science is balanced - as opposed to integrated - between life, earth and physical science, developing conceptual understanding and integrating mathematics, technology and decision-making. In other words, the activities included in PRIME Science are devoted to discipline-specific concepts, but in a balanced presentation rather than an interdisciplinary one.

Several major curriculum themes provide structure for grades six through ten (e.g., the earth in space, properties of matter, etc). Each curriculum unit begins with an application. The visually stimulating, attractively designed student supplements for each of the forty units contain the application, a summary of what students should know, what they need to learn, and the activities they can do.

The curriculum presents concepts more than once, in more than one context, and at increasing levels of sophistication and detail. Three traditional curriculum areas—earth science, life science, and physical science—are presented and interrelated each year in both the middle school and high school units. The middle school and high school portions of the curriculum complement each other, but could be implemented independently. Prime Science also addresses the technology standards, and includes technology-based inquiry activities, such as Internet laboratories. Themes like health, earth in space, properties of matter, recycling, technological solutions to problems, and environmentalism run throughout the curriculum.

Effectiveness

A detailed review of PRIME Science by Kendall Hunt and The Vermont Institute of Math, Science and Technology is available on the Web at: http://www.vismt.org/curriculum/progs/pdfs/docs/prisci.pdf. This report evaluates the curriculum in a wide array of categories, including the use of multiple perspectives, opportunities for reflection, personal relevance, active inquiry, and collaborative learning. The reviewers rated the program as very effective in all categories, and deemed it to be fully consistent with the Vermont Science Standards. In addition, the Los Angeles Systemic Initiative has concluded:

> *PRIME SCIENCE is an exemplary, standards-based integrated science program that is recommended by the Los Angeles Systemic Initiative (LA-SI), the National Science Foundation, and the National Science Teacher's Association. Integrated units of physics, chemistry, biology, and earth science along with critical thinking skills are revisited at increasingly complex levels.*

Professional Development and Support

This full curriculum, developed with National Science Foundation funding, includes a substantial set of teacher materials, such as teacher's guide volumes 1 and 2, teacher transparency sets, and assessment materials.

Costs and Technical Requirements

Costs for the curriculum were not provided on the web site. Interested parties were encouraged to call.

Science and Sustainability

Contact information

Web site: http://www.lhs.berkeley.edu/sepup

Developer: The Science Education for Public Understanding Program (SEPUP) may be reached at SEPUP, Lawrence Hall of Science, University of California at Berkeley, 94720-5200. Phone: 510/642-8718. E-mail: sepup@uclink4.berkeley.edu

Commercial Distributor of SEPUP modules: Lab-Aids, Inc., 17 Colt Court, Ronkonkoma, NY 11779. Phone: 516/737-1133; Fax: 516/737-1286. Web site: www.lab-aids.com/sepup/.

Description

Science and Sustainability (S&S) is a tenth grade, full year curriculum that uses the theme of sustainability as the basis for investigating a range of integrated, issues-oriented science topics. A product of the Science Education for Public Understanding Project (SEPUP), S&S includes activity kits to support student investigation and incorporates technology to support student inquiry and professional development for teachers. SEPUP units feature activity kits, which include a variety of materials that are used during student-driven investigations. The teacher's guide includes activity extensions, a complete assessment package, and suggestions for integrating S&S with technology and literacy.

The primary goal of S&S is to provide students with opportunities to gather and weigh evidence that can inform public decisions about science, technology, people, and the environment. SEPUP has developed a variety of curricular materials that provide a structure and activities for this issues-oriented approach.

The course is split into four parts: Living on Earth, Feeding the World, Using Earth's Resources, and Moving the World. The curriculum moves from developing a basic understanding of what organisms need to survive to how people can sustain and improve their quality of life. Students engage in investigation and debate on topics such as development in Third World countries, the role of genetic engineering in agriculture, and the trade-offs faced in providing energy and food for a growing human population.

In addition to addressing the role of technology from the standpoint of sustainability, S&S also uses a variety of technological resources to support teaching and learning. Several activities within the curriculum are supported by a collection of Web resources maintained on SEPUP's Web site.

S&S also integrates two educational technologies:

- *STELLA* is a professional-level tool for modeling system dynamics in a variety of scientific, mathematical, and economic domains. SEPUP has partnered with the makers of STELLA and the National Computational Science Alliance to produce a set of models that students use to learn about population dynamics.
- The *Progress Portfolio* is software designed to help students document and reflect on the work they do in computer-based settings. The Portfolio consists of "an integrated suite of screen capture, annotation, organization, and presentation tools."

SEPUP encourages the use of the Portfolio along with STELLA to provide students with the means to document and annotate the models they build.

As part of the development process, SEPUP courses are field tested by scores of teachers for at least two years prior to publication.

Effectiveness

Several studies have evaluated SEPUP year-long courses and shorter SEPUP modules (Kelly, 1991; Koker, 1992a; Koker, 1992b; Koker, 1996; Koker & Thier, 1994; Samson & Wilson, 1996). The focus of these studies has been student beliefs about science (especially whether or not science is relevant to their lives and their communities), the importance they assign to evidence in scientific reasoning, and their understanding of the subject matter.

Results from multiple studies suggest that, in the course of using the SEPUP modules, students become more convinced that science is relevant to their lives (Kelly, 1991; Koker, 1992b). These results report on pre/post measures for SEPUP classrooms and do not compare these results to a control classroom.

A longer study comparing students in another SEPUP course—Issues, Evidence and You—to a set of comparison students showed that the SEPUP students performed significantly better on open-ended questions that asked them to provide evidence to support explanations for scientific phenomena (Koker, 1996). Samson and Wilson (1996) reported similar findings for a pilot evaluation involving over 70 teachers. In this study, SEPUP students outperformed a comparison group in tasks that required students to use scientific evidence to support problem solving. In addition, SEPUP students indicated that they felt science was more relevant to their everyday lives than did the comparison group.

While none of these studies reports on the effectiveness of S&S, which has recently been revised, the studies do offer evidence to suggest that the issues-oriented approach that SEPUP brings to curriculum development is sound.

Studies by Kelly (1991) and Koker (1992a; 1992b) suggest that the use of SEPUP materials is consistent with an inquiry-based approach to teaching science, and that teachers who use SEPUP materials are likely to employ "positive teaching strategies and professional behaviors" such as participation in on-going, in-service opportunities. The limitation of these two studies is that they were based on teacher self-reports and were primarily focused on small groups of teachers in school systems that were adopting SEPUP.

Professional Development and Support

SEPUP supports professional development in a variety of ways. Weeklong summer workshops held in Berkeley focus on planning the use of SEPUP materials and discussing strategies for using these materials with a diverse student population.

Regional workshops, organized by local SEPUP leaders as well as staff from Berkeley, provide additional opportunities for teachers to learn about SEPUP materials.

In addition, SEPUP supports professional development by maintaining a virtual office as part of TAPPED-IN, a Web-based online community where teachers from around the country can engage in real-time discussion about teaching and learning issues.

Costs and technical requirements

A full classroom kit for Science and Sustainability, which includes materials to support up to 100 students, costs about $5,500 through Lab-Aids. This investment is basically a one-time expense, since most of the kit components are not consumable and can be reused. Lab-Aids provides a complete breakdown of what is included in the kit, with information about which elements are consumable, on its Web site. In addition, components from the kit are available for purchase separately for teachers who do not want to purchase the complete kit.

Teachers interested in using STELLA or the Progress Portfolio must contact the publishers of the software directly. STELLA will run on Windows or Macintosh platforms and is available at an educational discount directly from High Performance Systems (http://www.hps-inc.com/). Progress Portfolio currently runs only on Macintosh computers and is available free of charge at: http://www.progressportfolio.nwu.edu/. Teachers can access TAPPED-IN (http://www.tappedin.org/) at no cost, using any Web browser that supports Java.

Virtual High School

Contact information

Web site: http://vhs.concord.org/

Address: Project Coordinator, Virtual High School, 37 Thoreau Street, Concord, MA 01742, Phone: 978/369-4367; Fax 978/371-3995; E-mail: vhsinfo@concord.org.

Description

The Virtual High School (VHS) project offers schools opportunities for teachers to teach specialty courses online and for students to take courses not offered at their own school. During the 1999-2000 academic year, over 80 schools and 1,800 students participated in VHS, and teachers offered more than 20 different online science courses. The VHS project is sponsored by a grant from the Department of Education, and runs through 2001.

The VHS model requires collaboration among schools. A participating school donates one period of a teacher's time, and that teacher offers an online course (also called a NetCourse) for up to 20 participants from other schools. In exchange for this contributed teaching time, up to 20 students from the participating school can enroll in other courses that are offered through VHS. Note that this model requires buy-in at the school level; individual teachers cannot join the VHS collaborative.

VHS offers students the opportunity to take courses in a wide range of subject areas not offered at their own school. It offers teachers the opportunity to teach new subjects and to gain experience teaching in a new medium. VHS course offerings span the full range of the high school curriculum, not just science. Sample science offerings include courses on malaria, health, ethnobotany, evolutionary genetics, paleontology, astronomy, ornithology, ethnology and bioethics.

VHS replaces the traditional, didactic, lecture-based approach to learning with a combination of online courses for teachers and students that "fosters constructivist teaching practices and capitalizes on collaborative learning communities and cooperative online resources" (Hsi & Tinker, 1997). Courses are offered through VHS' Web site, which provides facilities for having class discussions; accessing syllabi, materials, and academic calendars; holding office hours; and assessing student work. Students and teachers may also interact through e-mail. For many classes, students are sent additional material by mail to support class activities. Site coordinators at each school are responsible for monitoring students locally and providing additional support as needed.

The VHS project's constructivist approach to teaching and learning, where students construct their own scientific knowledge by integrating new ideas and evidence with their existing understanding, can be challenging to implement in an online medium; for example, it is difficult to directly engage students in hands-on investigations over the Internet. However, VHS is addressing this challenge head on. The Teachers Learning Conference is a mandatory online seminar for teachers new to teaching at VHS. Its goal is to provide opportunities for teachers new to the program to discuss these issues with experienced VHS teachers and faculty prior to teaching a course, and it gives teachers opportunities to facilitate discussions and activities as part of the online seminar.

Effectiveness

Most of the evaluation that has surrounded the VHS, its NetCourses, and the Teachers Learning Conference has been focused on informing the redesign of the courses and the surrounding technological infrastructure.

A recent external evaluation of the VHS project by SRI International focused on documenting student and teacher experiences during the second full year of VHS (Espinoza, Dove, Zucker, & Kozma, 1999). The evaluation found improved teacher satisfaction with VHS courses, comparable course quality with in-school offerings, fewer technical difficulties using VHS, and better defined roles for teachers, students, and site coordinators. While these results do not speak directly to improved student performance, they do point to success in helping teachers adapt their practices to support inquiry-based strategies in an online environment. As more and more schools adopt information technology, it will become more and more important for teachers to be able to facilitate learning online. VHS offers a good professional development model for teachers interested in using information technology for distance learning.

The primary challenge facing VHS as it continues to grow is sustaining the quality of the courses it offers and of the instruction that occurs in an online environment. VHS is addressing this issue through professional development (the Teachers Learning Conference, described below) and through a new review process for approving courses. A NetCourse Evaluation Board (NCEB) has been established to assure course quality, and, since teachers must participate in an online course themselves before offering courses to students, VHS faculty and the NCEB hope to identify questionable course offerings before students enroll.

Professional Development and Support

Prior to teaching an online course, teachers participate in a mandatory NetCourse known as the Teachers Learning Conference (TLC). The TLC is a 15- to 18-week online course, run like a graduate seminar, that introduces teachers to constructivist teaching models and provides training for supporting online courses, including managing online discussions, supporting student work remotely, leveraging available technologies to best use, and assessing learning online. Its culminating activity is to design an online course. Since its inception in 1997, the TLC has undergone at least two revisions to better meet the needs of teachers (Hsi, 1999). Research evaluating the successive iterations of the TLC has documented specific design principles that seem to contribute to an effective social context for learning. These design principles are being used to information the ongoing redesign of the course, as well as serving as valuable heuristics for teachers who are themselves teaching courses online.

Costs and Technical Requirements

Participation in VHS is a serious commitment and must be undertaken with support at the school or district level. VHS expects a $50,000 in-kind commitment from participating schools. (Complete details are available on the VHS Web site; follow the "How to Join" links.) Schools must provide Internet-ready computers and some staff time (0.2 FTE) for a VHS site coordinator who supports students and teachers. Additional technical and administrative support is provided through the Concord Consortium.

2.2 Synchronized collaborative courses

We define synchronized collaborative courses as courses in which students in different geographical locations participate in the same activities and interact with one another to some extent. For example, as part of a weather measurement unit, students from different parts of the country or the world might make weather measurements and then compare notes on weather patterns in their respective locations. These curriculum units can require a commitment of anywhere from a few days to a few weeks to the full semester. The programs we review work best when several classrooms use the curriculum at the same time and share their findings with each other. The programs draw on communication technologies to coordinate activity and discussion among the school sites.

The curricula described here take advantage of communication among sites to share quantitative and qualitative data that are geographically dependent and/or time-sensitive, such as weather data, astronomical observations, or water quality data. Students at a particular school are sometimes required to serve as the "resident experts" in a particular kind of data, and must communicate with students at other sites to help compare their local environments.

To support discourse among schools, synchronized collaborative courses draw on a variety of communication media, including e-mail, discussion forums, and the Web. Other technological tools, such as electronic probes that can measure temperature, pH, and other factors, are often used to facilitate data collection and analysis.

A strength of the synchronized collaborative approach is that it can foster a "community of learners" and create a natural audience for student work. Participation in this community also allows students to engage in scientific discussion and debate, asking questions and presenting ideas and evidence to students in distant classrooms. An important criterion for evaluating the programs described here is the degree to which they permit students to participate in these scientific practices, which are essential to the scientific enterprise but are often overlooked in the curriculum.

Global Lab

Contact information

Web site: http://globallab.terc.edu/home.html

Email: gl@terc.edu

Address: Kendall/Hunt Publishing Company, 4050 Westmark Drive, Dubuque, IA 52002.

Tel: 800/258-5622, ext. 1041

Description

Designed by researchers at TERC, Inc., Global Lab provides a telecommunications network that links schools in a shared curriculum of interdisciplinary inquiry activities for grades 8-10. Drawing on the latest in Web-based technology, students investigate the health of the planet by focusing on biological, chemical, physical and geographical issues at their own "study site." Teachers can select from a set of Global Lab modules or a full year curriculum.

Using the Global Lab modules, students analyze their study site, take measurements of quantitative variables, work with physical and biological models, and summarize their findings. Funded by the National Science Foundation, the curriculum meets national standards and benchmarks. Global Lab is designed to help students develop scientific investigation skills incrementally. While early activities help to guide students' activities, the curriculum culminates in an extensive investigation that students plan and carry out independently.

An important feature of the project is the interaction between students at different study sites. An extensive Global Lab Web site allows students from different sites to exchange information, review one another's findings, and search for relevant perspectives. Students have Web authoring and support tools, enabling them easily to generate Web pages and publish their work. Students can upload their data, or download data from other study sites. Thus, local investigations can be connected to a more global understanding of environmental issues.

The Global Lab curriculum focuses on the following concepts: the interaction of matter and energy; biochemical cycles; biomes and biodiversity; and the earth as a system. These concepts provide students with access to conceptual content from across many disciplines of science (e.g., biology, chemistry, physics, and environmental science). Each activity is accompanied by assessments that are provided to teachers in the Global Lab teacher's guide. The curriculum contains suggestions for teachers about the most effective ways to assess students' work. The "Learning Objectives" sections at the beginning of each investigation suggest the ideas and skills that should be the focus of the teacher's assessment. Teachers are particularly encouraged to use portfolios and group assessments, which are described in detail.

The Global Lab curriculum consists of a curriculum overview that provides a welcome, orientation, and support for the telecommunications system and five units:

- Unit I: Becoming a Global Community
- Unit II: Investigating Our Earth: Land
- Unit III: Investigating Our Earth: Water
- Unit IV: Investigating Our Earth: Air
- Unit V: Extended Investigations

Each unit is accompanied by a Teachers Guide, a student book (optional), and a set of instruments and supplies designed specifically for that unit. An annual Network Membership is also required for each unit, giving students access to the Global Lab Web Site.

Effectiveness

For the past five years, the Global Lab curriculum has been piloted at more than 300 school sites in more than 30 countries throughout the world. SRI International conducted a two-year evaluation of pilot work and has published a final report (Young, Haertel, Ringstaff, & Means, 1998). SRI's evaluation of student learning through scientific inquiry within the context of Global Lab shows improved learning as measured by written assessments. It also shows that students developed positive attitudes toward science, gained understanding of scientific habits of mind (curiosity and perseverance), and gained understanding of the role of collaboration in scientific inquiry. The report also notes that professional development is crucial to implementation of many "rigorous, inquiry-based, standards-based curricula. (Young et al., 1998)."

Several additional published accounts of the effectiveness of the Global Lab curriculum are available. For example, Berenfeld (1994) describes the use of the telecommunications network to support student learning of investigation skills. Ruben (1994) reviews several computer-based environmental education projects, including Global Lab. More recently, Borst (1997) provides a detailed description of one teacher's experience with the Global Lab Air Quality activity, focusing on the techniques students used to collect indoor air quality measures and on the impact of the telecommunications network.

Professional Development and Support

Global Lab provides substantial support for professional development. In addition to the teacher guide, Kendall/Hunt Publishing Company and TERC, Inc., jointly conduct convention workshops, teacher in-service workshops, and other training events. The Global Lab staff supports participants by providing innovative curricula, access to professional scientists, and low-cost, high-tech instrumentation. Teachers receive additional support through online computer tutorials.

Costs and Technical Requirements

This project has recently changed status from a funded research project, supported by grants from the National Science Foundation, to a published curriculum package. As part of this transition, the project has withdrawn its support for teachers for the 1999-2000 school year, but it plans to resume its services under a new publisher and subscription format for which costs are not yet available.

Global Learning and Observations to Benefit the Environment: GLOBE

Contact information

Web site: http://www.globe.gov/ or http://www.globe.gov/fsl/welcome.htm

For information or assistance within the U.S., contact the GLOBE Help Desk at 800/858-9947 send email to: info@globe.gov.

Description

The GLOBE project has three major goals: "to enhance the environmental awareness of individuals throughout the world; to contribute to scientific understanding of the earth; and to help all students reach higher levels of achievement in science and mathematics" *(GLOBE Teacher's Guide, Program Overview).*

Through GLOBE activities, students from elementary through high school investigate topics in earth science, including atmosphere, hydrosphere, land use, and soil. Participants include students from around the world. Based on early project reports, over 10,000 educators have been trained from 8,000 schools in 86 countries; By mid-November 1999, nearly 12,000 teachers worldwide had attended GLOBE Training Workshops.

A unique feature of this popular project is that students contribute to university and government research in planetary science by collecting data and adding their findings to GLOBE's Student Data Archive—a captivating notion for teachers and students alike:

> *Students in the GLOBE Program have reported data from over 4 million environmental measurements for use in scientific research! GLOBE students have been carefully taking observations in atmosphere, hydrology, land cover, and soils since April 10, 1995. These student data are being studied in schools on every continent and used by scientists seeking a better understanding of Earth's environment.*
>
> GLOBE Project Web Site (http://www.globe.gov/fsl/GB/)

When schools adopt GLOBE, thereby becoming "GLOBE Schools," their teachers gain access to curriculum materials and technologies that enable students to participate in data collection and other scientific learning activities. For each domain of scientific inquiry (e.g., atmospheric science), a particular government and university research center participates as the scientific partner. Primarily, this partnership entails using the student data in some research context, and reporting back to students online. Some communication between students and scientists is also supported. Schools are required to participate for a three-year period, and must meet the data collection requirements, which include work on weekends and school holidays.

Each day, students record aspects of the environment near their school, including temperature and climate data, and report their measurements. Research scientists and students alike can then draw upon these and other measurements from thousands of schools around the world to gain a better understanding of global environmental processes. Using computers, students can input their GLOBE data and receive high quality imagery in the form of satellite photos and graphical representations of temperature, climate and land use data. GLOBE provides online tools and materials to accompany a suite of learning activities. In addition, students make use of Web-based forms to enter the data they collect from their own school site, and to view any pertinent findings that scientists derive from these data. Students use a Web-based forum called GLOBEMail to communicate with other GLOBE schools, holding online discussions with teachers, students, and scientists.

The theory behind these activities is that students learn science by doing it. By participating in actual scientific investigations of the environment, students will gain knowledge of earth science and of the scientific process. Specifically, they will learn how to collect data, and they will get feedback about the quality and the uses of their data from the learning activities that accompany their participation. Students learn about data quality and measurement error, and gain some concepts in statistical analysis. More importantly, they learn about the nature of scientific inquiry in these areas of earth science: What kinds of questions are scientists asking? What data are contributing to those questions? What are the most effective methods for measuring those data?

The complexity of GLOBE activities increases as students move through the course. By performing easy activities at first, students gain some fundamental concepts that can help them in successive activities. GLOBE activities are designed to complement the teacher's curriculum. Teachers can choose the amount of time they want to spend on GLOBE, as long as they complete the required data collection activities. These activities can be carried out by one or more students and can be accomplished outside of regular class time. Supplemental learning activities are provided by the *GLOBE Teacher's Guide* and teacher workshops. In general, some time is spent in class on GLOBE-related topics every week, with a combination of on-going data collection, open-ended tasks, and structured learning activities. The time spent by teachers on GLOBE activities varies widely, according to the amount of time they have available within their curricula.

Scientists from an array of government agencies—including the National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), and the Departments of Education and State—have collaborated with GLOBE educators to develop reliable data collection procedures using low-cost equipment. The GLOBE project has educational partners as well as natural scientists, including researchers at TERC (Cambridge, MA) and Vanderbilt University. These educational researchers have developed activities to accompany the data collection, and they do research to assess the effectiveness of these activities. In addition, the GLOBE Project includes an evaluation team at Stanford Research Institute (SRI) that has prepared annual reports to document the program's overall effectiveness and make recommendations about its future directions.

Effectiveness

Two reports by SRI International (Year 1, in 1996, and Year 2, in 1997) indicate that GLOBE has been effective in meeting its goals (Means et al., 1997; Means, Middleton, Lewis, Quellmalz, & Valdes, 1996). These reports are available on the Web at: http://www.sri.com/policy/ctl/html/globe.htm#evaluation

To evaluate the project's first year, SRI surveyed a random sampling of 400 U.S. teachers who had received GLOBE training in 1995 and 280 teachers from the U.S. and abroad whose schools were actively submitting data to the Student Data Archive in school year 1995-1996 (Means et al., 1996). They also surveyed student activities in GLOBE classes at the 4^{th}, 7^{th}, and 10^{th} grade levels and visited 10 GLOBE schools. The SRI project evaluations included both descriptive and quantitative data, collected largely through electronic surveys. Students were asked about their involvement with GLOBE activities and their attitudes and beliefs about world systems and measurement issues. Teachers were asked about the ways in which they implemented GLOBE activities in their classrooms, the challenges they encountered in setting up the program, and their strategies for dealing with problems.

SRI supplemented the survey data with on-site observations and interviews. Students and teachers alike reported that they were more interested and aware of the environmental issues facing the planet and that they believed their data were contributing to scientific research. Students overwhelmingly liked the activities and said they were the best part of science class. Teachers were impressed with how much science students were gaining—in addition to data collection. In formal evaluations of the GLOBE Program, SRI has documented improved student achievement in key math, science, and geography skill areas.

SRI is collaborating with the Cognition and Technology Group at Vanderbilt University to develop student assessment tools that will provide teachers and students with evidence about how well students are meeting the GLOBE learning goals. These assessments are still in development, as part of a four-year project. The tools will assess students' understanding of GLOBE concepts as well as their ability to conduct and interpret GLOBE investigations. They will also provide information to GLOBE teachers for instructional decision making.

Overall, The GLOBE Project exemplifies the criteria we applied to projects in this review. The topics of inquiry are authentic, in the sense that they involve measurements of students' immediate surroundings. The questions that guide these measurements are personally relevant and engaging to students, and provide relevant science content. Technology is used in an innovative and effective way, and students are seen to benefit from the activities. Although we believe that the learning activities provided to teachers can be improved, the project activities provided are certainly contributing to students' understanding of science and mathematics. While GLOBE activities may be more accessible to some students in a class than to others, the program nevertheless allows all students to play an important role in information gathering. Furthermore, the GLOBE project excels in providing training and support for teachers, as we discuss below.

Professional Development and Support

The GLOBE model of professional development includes substantial teacher training by a highly qualified team of scientists, educators and technologists in workshops that last for as long as two weeks. In workshops conducted so far, contact hours have ranged between 40 and 46 hours. After receiving "GLOBE" training, teachers are expected to go back to their schools and help other teachers adopt the program. At present, schools must have two GLOBE teachers on staff in order to participate.

The *GLOBE Teacher's Guide* helps teachers learn to use the inquiry activities, and it suggests additional learning activities that they can incorporate into their curriculum. Teachers receive on-going support for participation in the GLOBE Project via online resources for teachers, updates to the teacher's guide, and Internet contact with project support staff. Being a GLOBE School involves participation in a program, with support provided via newsletters, e-mail announcements, and workshops, and local personnel. GLOBE also maintains a help desk, where teachers can receive live phone support at any time during their school day.

Another interesting form of ongoing support provided by the GLOBE Project is the organization of research conferences. These are summer programs where students and teachers and scientists are able to connect with their broader community. For example, The University of Arizona hosts a GLOBE Teacher and Student Research forum to help learn how to use GLOBE data for student research projects. The University of Arkansas hosts 400 students and 100 teachers from elementary through high school, who attend the conference to present their own school's measurements, ideas and challenges. GLOBE scientists work with students to make GLOBE measurements at various study sites. In July 1999, a conference was held for GLOBE scientists, where they presented findings based on GLOBE student data.

Costs and Technical Requirements

The measuring instruments needed to participate in the GLOBE project (for observations in Atmosphere/Climate, Hydrology, Land Cover/Biology, and Soils) cost approximately $600. Additionally, schools must provide teachers and students with computers that are connected to the Internet (at least one per classroom). Perhaps the most serious requirements are in the category of teacher training and commitment. GLOBE requires teachers to be trained at an official GLOBE training workshop where they are provided with educational materials (e.g., the handbook) and training in GLOBE measurement procedures, learning activities, and use of the Internet. As stated above, the project also requires participating schools to have at least two GLOBE teachers on staff.

One Sky Many Voices

Contact information

Web site: http://www.onesky.umich.edu/

Project Manager: Michelle Astolfi, One Sky, Many Voices, 1323 School of Education, 610 East University, University of Michigan, Ann Arbor, MI 48109-1259/

Phone: 734/647-7369; Fax: 734/763-1368

E-mail: onesky@umich.edu

Principal Investigator and Project Director: Nancy Butler Songer, Associate Professor, Science Education & Educational Technology, 1323 School of Education Building, 610 East University Ave., The University of Michigan, Ann Arbor, MI. 48109-1259. E-mail: songer@umich.edu

Description

One Sky Many Voices engages a group of classes simultaneously to study aspects of weather. Students become expert in a weather event such as a particular storm or in some aspect of weather such as wind, clouds, or inversion. Classes around the world can follow the same weather pattern and discuss its progress. Teachers can register their classes for courses at the Web site (registration is closed for 2000).

The intent of the program is to introduce teachers and students in K-12 classes to learning through use of computer technology in the classroom. The program is closely tied to standards that range from goals for students (e.g., "All students should develop the abilities necessary to do scientific inquiry and understandings about scientific inquiry.") to goals for teachers (e.g., "Teachers of science engage in ongoing assessment of their teaching and of student learning.").

Effectiveness

Published results show that fifth graders increase their understanding of complex ideas such as Coriolis force and that high quality, interactive discussion between students, teachers, and scientists occurs during typical projects in over 200 schools. (See papers on the web site: http://www.onesky.umich.edu under the Project Papers link near the bottom of the home page.)

Professional Development and Support

There are no initial teacher requirements for participation. OSMV directly supports the Detroit Public Schools with school workshops and teacher focus groups. Weekly on-site support from graduate students is provided for participating teachers through the duration of the eight-week program.

Costs and Technical Requirements

OSMV requests a $25.00 participation fee to help defray the cost of publishing the curriculum binder, duplication of an Internet-smart CD-ROM, and mailing expenses. No teacher is excluded from participating in the program, whether or not the fee is received. Teachers are strongly encouraged to have access to computers that have an Internet connection.

2.3 Learning environments

Learning environments are computer-based instructional environments that combine curricula, classroom activities, and assessments into packages designed to improve teacher effectiveness and to provide a variety of cognitive and social supports for student inquiry. Typically, these environments provide a set of common support mechanisms that are available in multiple curricular activities.

Learning environments are usually designed to support several different curricula and are best used with multiple projects. Students develop a familiarity with the technology that can be leveraged in later projects. Learning environments free teachers to interact with students and invite students to engage in inquiry. These environments incorporate the results of cognitive research in activity supports such as hint giving, prompts for reflection, and connections to online discussions. Only a few learning environments exist for the high school market.

The Web-based Integrated Science Environment: WISE

Contact information

Web site: http://wise.berkeley.edu

The WISE home page provides access to the WISE curriculum, contact information, and resources for professional development and authoring partnerships.

Description

The Web-based Integrated Science Environment (WISE), is a browser-based library of middle school and high school level activities that enable students to critique real-world "evidence" from the Web, compare different scientific arguments, and design problem-solving approaches based on scientific principles.

The goal of the WISE curriculum is to supplement conventional instruction in science with activities that are personally relevant to students. These activities should deepen their understanding of multifaceted scientific issues, introduce them to scientific methodology, and enable them to gain lifelong learning skills, such as the ability to critique Web sites and to support their designs and conclusions with appropriate evidence.

Developed by the authors of this report and other researchers at UC Berkeley's Graduate School of Education, WISE draws upon extensive cognitive and educational research, including the Computer as Learning Partner (CLP) and Knowledge Integration Environment (KIE) projects, which brought together teachers, researchers, and scientists to design a curriculum that gives students a deep understanding of course content and to explore how computer technology can guide and support students' work. The WISE learning environment extends this research to provide a new curriculum for a wider range of scientific domains and school settings.

The WISE curriculum addresses science topics from an integrated perspective, seeking activities that cut across disciplinary boundaries and incorporate assessment. WISE units are currently available in the following areas: plant biology, use of animals in space research, passive solar energy and architecture, the nature of light, principles of energy conversion, earthquake predictions, Malaria control and disease vectors, frog malformations in North America, wolf population control, and water quality in local creeks and rivers.

WISE employs three basic templates to help organize student activities and learning materials:

· <u>Critique Projects</u>: Students examine diverse Web sites and critique them in terms of authorship, source validity, scientific claims, and evidence used to support those claims

· <u>Controversy Projects</u>: Students evaluate conflicting scientific arguments and formulate their own argument, supporting it with evidence

· <u>Design Projects</u>: Students design their own solution to a scientific problem based on evidence they find on the Web.

The WISE technology provides an organizational structure for students as they perform these activities, helping them reflect upon what they are learning, take notes, sort evidence, organize their ideas, and discuss their arguments online with peers. Many WISE projects involve hands-on data collection or observations, complemented by online modeling of observations or by design activities that incorporate lessons learned. Materials drawn from the Internet can give students access to scientific evidence, differing points of view, and visualizations (e.g., images, diagrams, animations or models). Students perform all work collaboratively, and are assessed in terms of their notes, arguments, models, and designs. Pre- and post-activity assessments are also provided for each activity. Technological features of WISE include a within-browser interface, allowing all student work to be performed online. Since no software need be installed on student machines, students can log on from home and continue their work from any machine that is connected to the Internet. "Inquiry Maps" within the interface help to guide students as they work through the sequence of activities within a project, while Amanda the Panda provides periodic cognitive guidance. All student data are stored on remote servers and maintained by advanced server and database technologies.

Curriculum authoring software has been developed to allow partnerships of scientists, teachers, and educators to create new activities. Classroom management tools support teachers as they implement WISE, including online and printable lesson plans, assessment software, and technology support tools that can send students online messages while they are running a WISE project. Online communities have been developed to link to additional online resources, peers, and mentors.

The WISE project staff has connected the curriculum to process and content standards at the state and local levels. WISE authors have shown how WISE activities meet the California State Science Standards, using mapping that can serve as a reference to teachers in other states, and they are currently matching the WISE learning framework with National Science Standards.

For students, performing a WISE project is generally a new kind of science learning activity. They first receive some preliminary instruction from their teacher about the nature of Internet materials and how these materials can provide a valuable source of evidence if reviewed with a critical eye. After they register online for the project, they work (with their partner) through a sequence of online activities. In one activity, for instance, students (in grades 7 - 12) explore passive solar energy hands-on by heating two cups of water simultaneously with a light bulb. They then go to the Web, where they explore several innovative house designs that vary in their credibility and in the sophistication and scientific validity of their designs. The WISE software prompts the students to critique the house designs, asking, Who wrote the web site? Is it trustworthy? What are the main principles of the design? After performing their critiques, students engage in an online discussion about the most effective passive solar designs.

To develop a curriculum that is personally relevant to students, WISE authors draw upon the World Wide Web for materials, representations, and the latest scientific findings. All WISE curricula are developed through repeated cycles of classroom trial and refinement.

Effectiveness

Classroom research over the last 15 years, summarized by Linn and Hsi (2000), has provided a theoretical framework for the design of science curricula that help students deepen and integrate their scientific knowledge by adding new ideas to their current repertoire and reorganizing their ideas. Many classroom studies have explored the role of technology in supporting this kind of learning. Linn and her colleagues have tried to determine what new activities can take advantage of this technology. Online graphing of data, for example, and electronic discussions are both activities that were not possible before the introduction of computers into the curriculum. Hsi and Hoadley (1997) studied the role of electronic discussions in supporting student design and refined the WISE design template according to their findings. Slotta and Linn (2000) explored the effect of advance organization information on students' ability to ask critical questions about evidence. This research informed the development of advance guidance for WISE curriculum materials. Many other studies have explored the role of Internet-based activities in a science curriculum.

Based on this research, Linn has identified four principles for effective curriculum design, which WISE incorporates:

- <u>Choose accessible topics</u> and use models that students understand
- <u>Make student thinking visible</u> by using visualizations and representations
- <u>Help students learn from each other</u> using collaborative tools, online discussions, and group projects

- Foster lifelong learning with reflection, critique, argument comparison and design activities.

WISE projects are meant to serve as capstone activities, providing opportunities for students to reflect on material they may have covered in class but haven't yet applied in any meaningful way. Students who perform a WISE project demonstrate reliable learning gains, as measured by assessments that reflect both content and process standards. In other words, WISE activities help students develop a more coherent understanding of the science content, while also gaining lifelong learning skills. By performing activities in which they are asked to critique, to compare arguments, and to design solutions or models, they are practicing scientific reasoning, and gaining important perspectives on the nature of science.

Professional Development and Support

Several research projects are exploring the most effective ways to help teachers adopt the new technologies, curriculum, and pedagogical approaches of WISE. A whole-school project is comparing how middle school teachers apply the WISE materials and is examining the role of a mentor teacher in modeling effective approaches. Based on earlier research in teacher adoption of WISE (Monaghan, Slotta, & Cuthbert, 1999) as well as the new whole-school study, the WISE Project staff has developed a curriculum and a set of support tools for an online NetCourse that helps teachers adopt WISE successfully.

WISE provides an online community through which teachers can access the assessment and classroom setup tools, try out demos of new WISE activities, participate in authoring partnerships with natural scientists and educational researchers, and engage in Web-based discussions about teaching with WISE. Through the WISE online NetCourse, teachers can explore the new pedagogical ideas and approaches associated with WISE. Once teachers have begun using WISE, the project staff and other teachers in the WISE online community provide support by e-mail. Additionally, the online community helps connect new teachers with "WISE mentors" who can provide detailed assistance with specific curricula as well as more general pedagogical expertise.

Costs and Technical Requirements

Teachers may currently implement WISE free of charge, thanks to project support from the National Science Foundation. It is likely that school districts will eventually pay for access to the WISE materials, which they will make available to teachers within the district. Presently, teachers need only visit the project Web site (http://wise.berkeley.edu) to join the WISE teacher community and gain access to all curriculum, tools, and materials. To use WISE effectively, teachers must have access to computers in their classroom or to a computer laboratory with at least one computer for every two students. Computers must be connected to the Internet by means of a recent version of Netscape or Internet Explorer. To complete most WISE activities, teachers need approximately one week of continuous access to computers (five 45-minute periods).

WorldWatcher

Contact information

Web site: http://www.worldwatcher.nwu.edu/

E-mail: info-worldwatcher@letus.nwu.edu.

Description

WorldWatcher uses customized scientific visualization software and historical data sets to support investigation into phenomena such as global warming. The project staff has developed an eight-to-ten week curriculum unit called the Global Warming Project that is intended for students in grades 7 to 10. In this project, teams of students assume the roles of advisors to the heads of state for several nations, and must learn what they can about global warming so that they can advise their leaders about the various options each country faces. The project has four phases:

- An introductory activity that sets the context for the project
- A series of activities to help students understand temperature and how it varies over the planet, in normal circumstances

- A closer investigation of how the sun warms the earth and how the earth retains heat
- A final predictions and solutions phase, in which students explore various solutions for dealing with the problem.

Throughout the unit, students use WorldWatcher to view national demographic data as well as scientific data relating to global warming.

The Global Warming Project uses scientific visualization technologies to help students learn about earth science and other topics. Scientific visualization, a relatively recent use of computer technology to display location-based data such as elevation or population on a map, holds great promise for science education (Gordin & Pea, 1995). By translating numerical data, such as temperature, to a palette of colors (e.g. using shades of red to represent warmer temperatures and shades of blue to represent cooler temperatures) and displaying the results on a map of the world, WorldWatcher makes it possible for students to recognize patterns in the data that would be difficult to comprehend from the numerical data alone; for example, seeing quickly that the northern hemisphere is warmer during July than the southern hemisphere.

WorldWatcher gives students powerful tools for scientific visualization as well as support for interpreting and manipulating the visualizations they work with. Using WorldWatcher, students can engage in a variety of activities—expressive, interpretive, analytical, and inventive. The software allows students to annotate data, to make predictions by painting colors directly onto the world map, and to perform sophisticated analysis by overlaying multiple data sets, for example, to see the temperature difference between winter and summer. Online diagrams of systems such as earth's energy budget help to put specific data sets in context and indicate their relationship to one another. WorldWatcher also comes with an online journaling component that makes it possible for teachers to design customized worksheets or guides that students can use as they engage in the project.

The WorldWatcher staff is developing a full year curriculum that will be available for widespread field testing in the 2000-2001 school year. The full-year curriculum, currently being piloted in the Chicago area, is a "year-long, visually intensive environmental science curriculum centered on three key issues: the engineering of water in the Great Central Valley of California, the consequences of human activities on the biogeography of the Mojave Desert, and decisions regarding the future demand for electricity." This curriculum is targeted at grades nine to twelve and will include integrated assessments that are "closely linked to the national science standards."

Effectiveness

The WorldWatcher project has engaged in formative classroom research for several years (Edelson et al., 1999). Much of this work has focused on understanding how students use data visualization software and has contributed to the redesign of the software itself as well as to the development of a set of curricular activities that integrate the use of WorldWatcher into a traditional lab setting. Brown and Edelson's (1999) report on use of the global warming curriculum also draws on qualitative methodologies to argue that integrating technology with traditional lab investigation allows students to engage in authentic inquiry within a framework that is familiar to both students and teachers. They provide a case study of one student group to illustrate the nature of investigations that students pursue with the WorldWatcher curriculum.

Professional Development

The WorldWatcher project offers workshops and professional development opportunities as part of the Center for Learning Technologies in Urban Schools (www.letus.nwu.edu). In addition to these efforts, the project provides tutorials and an online support system to help teachers learn how to use the software. For teachers using the Global Warming curriculum, the project also maintains an e-mail list server that allows teachers to ask questions and discuss issues surrounding the use of WorldWatcher.

Costs and Technical Requirements

WorldWatcher software is compatible with Macintosh and Windows computers and is free. The software may be downloaded from the WorldWatcher web site, or may be purchased on CD-ROM (free, but shipping and handling charges may apply). Note that the data sets that accompany the software are rather large; teachers with slow Internet connections may prefer to receive the materials on CD. The software includes both online help and tutorials to guide novices through the use of the software.

2.4 Kit-based inquiry activities and CD-ROMs

This category of projects includes perhaps the greatest number of titles and authors. Many high quality CD-ROM and kit-based activities have been designed for students at all grade levels and for all science topics. Typically, these activities are self-contained, in the sense that they come with all the materials needed and require no supplemental software or curriculum in order to be used. Often, they are self-paced and self-guided inquiry activities that would be suitable for independent student work (e.g., from home or after school). There is a great diversity in this category, with some projects featuring elaborate kits that include hands-on activities, teacher-led discussions, and CD-ROM or Internet components. Others are quite simple, and may provide students with a supplemental inquiry activity.

CD-ROM technology emerged more than a decade ago as a means of providing large quantities of media-rich information -- usually hyper-linked to allow users to explore the information in a non-serial fashion. The earliest CD-ROMs contained little more than enhanced versions of available print material (e.g., encyclopedias or electronic hypertexts). Before long, however, curriculum developers found that CD-ROMs could provide a visually rich, self-contained “environment” in which students could explore science materials. For example, a CD-ROM could provide students with a wealth of hypertext materials about aquatic organisms as they undertake imaginary underwater adventures.

Designing a pedagogically sound inquiry activity is the greatest challenge for producers of CD-ROMS. Often, these products are marketed as open-ended explorations, and, indeed, are so open-ended that they provide virtually no guidance and have no learning goals. In these cases, the CD-ROM serves solely as a reference. In other cases, considerable thought and effort is invested in creating meaningful activities that help students explore the content in a productive way. We have sought examples of such effective design in the products that we review here. Other types of kit-based activities included in this category supply students with materials (e.g., images) via the Internet, enabling them to engage in specific inquiry activities.

In all such projects, there is a concern that students will fail to utilize the kit-based materials effectively. Indeed, an even greater concern is that teachers will fail to appreciate the importance of their own role in guiding the use of kit-based or CD-ROM activities, which could result in students being left to their own devices with the materials, as a sort of "edu-tainment" activity. While playing around in a CD-ROM could provide hours of fun, it is certainly not an effective approach to inquiry-based instruction: the teacher plays a vital role in all such activities. Unfortunately, even the projects we review here rarely meet our criteria for professional development. Generally, these projects consist of a high quality set of materials, very good intentions relating to student inquiry, and varying levels of support for students and teachers. In this section, we review the strongest candidates, in terms of our criteria.

Cyber-Ed CD ROMs

Contact information

Web site: http://www.cyber-ed.com/start.html/

Email: info@cyber-ed.com

Address: CyberEd Inc., P.O. Box 3037, Paradise, CA 95967

Phone: 530/872-2432

Fax: 530/872-2445

Description

CyberEd, Inc., is an educational software company that develops and markets multimedia products for high school and college biology and chemistry. Founded in 1995 by Richard and Laura Carle, pioneers in the educational technology industry, CyberEd develops all its materials in house. CyberEd's award-winning Interactive Biology Multimedia Courseware Series has emerged as the focus of its CD-ROM development efforts. In 1999, the company announced an increase in the number of titles in that series from 24 to 32—the largest selection of multimedia biology software currently available.

The CyberEd CD-ROM activities supplement traditional science courses by using 3-D animations, video clips, and professional narration to address difficult biological concepts. Each CD-ROM is designed to correspond with a chapter from one of two biology textbooks published by Prentice Hall: *Biology, The Living Science* or *Biology, 5th Edition* (both authored by Miller & Levine). The programs are designed to support most state and federal guidelines for science education. Teachers or other registered users can also access supplemental materials from the CyberEd Web site. Titles in the Interactive Biology Multimedia Courseware Series include: Arthropods, Evolution, Mitosis, Biochemistry, Mollusks, Biology, Exploring Biology, Food Chains & Webs, Photosynthesis, The Biosphere, From DNA to Protein, Birds, Fungi, Blood and Immunity, Genetic Engineering, Investigating Heredity, Biomes, and many more. Additional titles are provided in chemistry, including Atomic Structure, Bonding, Formulas, Equations and Stoichiometry, Compounds, Periodic Table, and Properties of Acids, Bases and Salts.

All activities are supported with substantial "Study Guides" that help students and teachers alike to make effective use of the curriculum. Explorations vary, but include data analysis, predictions, and explanations of chemistry and biology simulation. Student assessment materials in the form of problem sets, quizzes, and full tests are also provided.

Effectiveness

As is the case with other CD-ROM or activity kits, CyberEd, Inc., does not cite research to demonstrate the effectiveness of its materials for student learning. We chose to evaluate its products, because they have been favorably received by the educational community and have been adopted by the educational publishing community. CyberEd, Inc., won the 1998 and 1999 Educational Software Review Award (EDDIE) for the Best High School Science Software. Additionally, the National Educational Media Network has honored CyberEd's Interactive Biology Multimedia Software Series with its Bronze Apple award, widely recognized as a standard of excellence in educational media.

Professional Development and Support

Supplements that accompany each title in the series provide professional support to teachers. These supplements include descriptions of teaching objectives, study guides for students, quizzes and exams, and a glossary of terms. Each study guide reinforces and expands upon a major biological theme presented in the program. The Quiz Pac provides quizzes that reinforce the study guide. The Comprehensive Exam provides a hard-copy exam. Each package of Supplemental Curriculum Materials contains an Answer Guide with answers to the Quiz Pac and the Comprehensive Exam. The Glossary defines terms introduced in the program and the supplemental curriculum package. There is no additional charge for these materials. Registered educators can also download supplemental materials from the CyberEd Web site, which includes a discussion forum for CyberEd teachers. The Web site provides a good supply of science resources, lesson plans, and standards. Teachers can also download shareware that supports their grading and classroom management and receive “give-a-ways” (e.g., a free poster of cell structure is currently available).

Costs and Technical Requirements

The cost of these materials ranges from $99 to $140 for a single topic, although discount prices are available for purchases of a larger series of titles. For example, the cost for a complete 35-part series (in the year 2000) is $3,234.95. Lab pacs are also available at a discounted price to accommodate larger numbers of computers. Working together with a major leasing company, CyberEd, Inc., has also developed a lease financing program tailored to school budget constraints.

The Cyberlearning Collection CD ROMS

Contact information

Web site: http://www.cyberlearn.com

Address: Digital Studios, 209 Santa Clara Ave., Aptos, CA 95003

Phone: 800/499-3322; 408/688-3158 (from outside the U. S.)

Description

A collection of CD-ROM-based activities, the CyberLearning Collection includes several products designed to address topics that its developers feel are important to the appreciation and understanding of living systems and technology.

In the "Task Force: Environmental Investigations Kit," for example, high school students participate in inquiry activities relating to the environmental controversies surrounding restoration of salmon populations in the Pacific Northwest. These activities are inspired by a spirit of environmental awareness and a belief that curricula that address political and scientific controversies can help students gain critical thinking skills.

The kit—composed of a videotape, two CD-ROMs, a teacher's guide, and a World Wide Web (WWW) site—exposes students to the tensions of opposing opinions regarding the maintenance of salmon populations in Washington and Idaho. The controversy involves the diverse perspectives of environmentalists, fishermen, politicians, Native Americans, navigation interests, and the hydroelectric power industry. The inquiry-based curriculum asks students to consider the environmental data and evidence cited by all these groups and to consider various proposals for salmon restoration, some of which are quite complex from a policy and scientific perspective. The series consists of four units: Natural History, Hatcheries and Harvest, The Hydrosystem, and Management Plan.

Within each unit, students explore "Concepts and Issues" and then perform a series of investigations that include role playing, data analysis and classroom debates. Teachers can divide the class into "special interest groups" for each stakeholder group or agency involved in the conflict. Each group is responsible for creating a solution to the problem and supporting it with environmental and economic data. Students in the various groups receive specialty assignments corresponding to professional roles (e.g., ecologist, sociologist, economist, or data specialist). The groups collaborate, cooperate with other groups, negotiate, form coalitions, and debate. Each activity includes a set of questions that help guide the students' investigations. Each CD-ROM contains supporting information, including video clips of the major stakeholders in the conflict, written reports from public and private agencies, data in the form of graphs and tables, and references to the literature. Students also have an Internet link to the project Web site where they can access additional information about the salmon restoration issue, as they seek to put the salmon back on the road to recovery while satisfying the interests of industry.

The Electric Biology Series, a more recent set of activities created by Digital Studios, explores ecosystems, energy flow, chemical cycles, and human impact. In a recent review article, the Digital Studios developers explained their motivation for producing curricula that focus on environmental controversies:

> *The resolution of the conflict between those who wish to preserve the natural environment and those who wish to exploit natural resources provides a unique opportunity to assist students in the development of critical thinking skills. One does not have to look far for examples: the preservation of old growth forests, coral reefs, the Everglades, the marshland in that empty lot behind the school, each conflict provides a captivating case study for investigation.*
>
> Nolan and Nolan, 1997

Effectiveness

The CyberLearning Collection has received glowing reviews from teachers and educational associations; however, no research is available to describe student learning. We have included it in our evaluation, despite the lack of research, because its goals and approach align closely with our criteria. Generally, CD-ROMs and kit-based activities provide a wealth of content and multimedia resources that can be used effectively for instruction if teachers are skillful in adopting and adapting them to their own curriculum. We chose to review the CyberLearning Collection, because it focuses on authentic inquiry, it provides materials to support teachers, and it has received highly favorable reviews. We excerpt some of the favorable comments, below, with the caveat that they are anecdotal accounts, not founded on educational research.

> *This is the best software I have seen that uses inquiry learning for principles of ecology combined with outstanding photography of coral reef inhabitants. I strongly recommend Coral Kingdom to teachers who use inquiry teaching…*
>
> Petrovic and Lavity (1998)

This software represents a real step in what is possible when combining computer technology and the INTERNET. This represents inquiry learning at its best! There is nothing "cookbook" about the program—the students have to gather data and create position statements from the students' perspective. Whether you care about salmon or not, the software is an excellent vehicle to help students learn inquiry learning techniques

Boone (1998)

Task Force: Salmon Preservation is more than just two CD-ROM's loaded with environmental data. It is a generous package of resources that allows students to gather information about the environment, complete worksheets, write reports, and discuss ideas with others via the Internet. This is perfect for teachers who want to emphasize data collection, group brainstorming, and interdisciplinary activities that lead to relevant problem solving.

Garcia (1998)

Professional Development and Support

The Environmental Investigation Kit comes with an extensive Teacher's Guide to help the instructor set up the computer, and it provides useful hints about instruction in an inquiry and role playing context. In addition to the manual, there is a short video that provides an overview of the salmon problem and shows how to use the TASK FORCE program. The video is useful in presenting the basic salmon problem and in helping teachers and students alike to quickly grasp how to manipulate the program.

Costs and Technical Requirements

One benefit of these CD-ROM activities is that most classroom computers are capable of utilizing them. The only requirements are a fairly recent Macintosh or IBM/PC compatible machine with a CD-ROM drive (2x format preferred), 8 Megabytes of RAM, and a 256-color (minimum) monitor.

Many different pricing structures are available. Typically, each CD-ROM kit is priced at $149, and includes a two-volume CD-ROM library, a videotape for supporting students and teachers, and a teacher's guide. CD-ROMs are also provided in a "lab pack" format, which includes several versions of the CD-ROMS for a laboratory setting.

Hands-On Universe

Contact information

Web site: http://hou.lbl.gov/index.html

Address: Dr. Carl Pennypacker, Lawrence Berkeley Laboratory, Building 50, Room 232, Berkeley, CA 94720

Phone: 510-486-7429

E-mail: pennypacker@csa2.lbl.gov

Description

Developed by the Lawrence Hall of Science at UC, Berkeley, Hands-On Universe (HOU) is a curriculum that enables students to investigate the universe while applying tools and concepts from science, mathematics, and information technology. HOU is a collaboration of the Lawrence Hall of Science, TERC, Inc. (Cambridge, MA), Adler Planetarium (Chicago, IL), and Yerkes Observatory (Williams Bay, WI), as well as a network of educators and astronomers from all over the world.

HOU seeks to engage students in authentic inquiry activities in the area of astronomy. The goal of these activities is for students to come up with answers to questions (of their own, or from the curriculum) through investigations of real astronomical images from telescopes, using software analysis tools much like those that professional astronomers use. Ideally, students working in the most advanced of the HOU activities could participate in real astronomical research (e.g., potentially discovering new supernovae).

Using the Internet, HOU participants request observations from an automated telescope, download images from a large image archive, and analyze them with the aid of user-friendly image processing software.

The HOU staff photographs astronomical objects (CCD images) with telescopes and processes the images. Students may request specific images. Teachers download these images, in accordance with pre-designed curricular activities or customized ones. Students then use the software provided to engage in real research projects in astronomy. Teachers receive training in the use of materials and are supported by a network of astronomers. Activities focus on in-depth use of information technology (e.g., image processing), data analysis, and mathematical problem solving along with the following topics in astronomy: identifying astronomical objects and features, measuring size, measuring brightness, exploring color, discovering supernovae and asteroids, tracking Jupiter's moons, and determining the mass of Jupiter.

HOU's high school curriculum integrates many of the science and math topics and skills outlined in national standards into inquiry activities.

Effectiveness

The effectiveness of Hands-on Universe in terms of student learning is currently being evaluated in conjunction with the Third International Mathematics and Science Study, with support from the National Science Foundation. In the meantime, teachers are enthusiastic about the project, with several hundred now participating. This level of participation involves thousands of students.

Professional Development and Support

In previous years, teachers learned the HOU curriculum by attending a one-week intensive workshop for two successive summers. While no on-going support is provided, teachers are connected into a network of HOU educators and researchers. Currently, the HOU project is studying the effectiveness of distance learning techniques for training teachers about HOU materials and activities. As part of this study (funded by the National Science Foundation), high school teachers will be assigned randomly to one of several plans:

- An intensive one-week course taught by one or more experienced HOU leaders.
- A self-paced course using the new HOU Professional Development CD-ROM and World Wide Web distance-learning tools.
- Two short (half-day to one-day) workshops, supplemented by a self-paced course using the new HOU Professional Development CD-ROM and WWW distance learning tools.

- Two short (half-day to one-day) workshops supplemented by a moderated WWW distance learning course using the new HOU Professional Development CD-ROM and distance learning tools.

Costs and Technical Requirements

The cost to schools or teachers for HOU curriculum materials is approximately $100. Additional costs for software (approximately $50) and telescope network access (about $150 per school) are involved as well. No information was available concerning the cost of professional development training or on-going participation.

Ocean Expeditions: El Niño

Contact information

Web site: http://www.planetearthsci.com

Ocean Expeditions: El Niño was developed by Planet Earth Science and is distributed and supported by Tom Snyder Productions. For more information about Planet Earth Science, including downloadable copies of the teacher's edition of Ocean Expeditions: El Niño, visit the Web site or contact the company at Planet Earth Science, 2656 Montrose Place, Santa Barbara, CA 93105. E-mail: PES@PlanEarthSci.com.

To purchase Ocean Expeditions or get information about Tom Snyder Productions, visit www.teachtsp.com or contact Tom Snyder Productions, 80 Coolidge Hill Road, Watertown, MA 02472. Phone: 800/342-0236; Fax: 800/304-1254; E-mail: ask@tomsnyder.com.

Description

Ocean Expeditions: El Niño is a CD-ROM-based virtual research expedition in which students draw on a variety of meteorological data, including satellite imagery, archival climate data, and climate models, to determine whether an El Niño event is occurring and what the implications of the event might be for the global climate.

The curricular unit runs about six days and covers meteorological and oceanographic information, including ocean currents, winds, clouds, and other factors that contribute to global weather phenomena like El Niño and monsoons. In addition to a CD-ROM, the curriculum includes student reference books and a comprehensive teacher's guide. The teacher's guide discusses the relationship of the unit to national and California standards. Of particular interest is the developer's emphasis on meeting national standards relating to science as inquiry.

Ocean Expeditions is intended to be used by teams of four students, who are assigned to a research ship and are given the task of determining whether or not an El Niño event is developing. The investigation is set in the early 21st century, and the program is designed so that the outcome varies each time the program is used; an El Niño will be present approximately half the time.

Each member of the team adopts one of the roles of navigator, communications expert, data collector, and data analyst. Students move about the ship using virtual reality technology, and collect and analyze data as they navigate around the globe. Several QuickTime movies are available to provide just-in-time instruction about specific climate topics.

Students have access to several scientific tools to support their research. The Data Archive provides students with access to eight years of archival data from the National Aeronautics & Space Administration (NASA) and the National Oceanic and Atmospheric Administration (NOAA), including data on sea surface temperature, surface currents, surface pressure, surface wind, clouds, and precipitation. Students can compare this data to current conditions at any point during the project.

A series of questions designed to assess the students' investigations and analyses of data are embedded into the investigation itself. The teacher's guide provides a rubric of sample answers for each of these questions. The students' final report summarizes their findings on the current climate and cites evidence either supporting or refuting the claim that an El Niño is currently underway.

Originally developed through grants from the National Aeronautics and Space Administration (NASA) and the Department of Energy, Ocean Expeditions is currently marketed through Tom Snyder Productions.

Effectiveness

No specific research studies have been conducted on the impact of Ocean Expeditions in the classroom. The chief claim made by the developers for the value of the curriculum is based on winning the 1998 Codie Award for best curriculum software for secondary or post/secondary education. The Codie Awards are conferred by the Software & Information Industry Association (SIIA) for excellence in software; the awards are voted on by the press and SIIA members.

The strength of Ocean Expeditions lies in placing students in the role of investigative scientists who must gather and make sense of climate data in order to determine whether or not an El Niño is occurring. The challenge posed to students is authentic, the results are not predetermined, and the unit provides access to relevant data and tools that support the analysis of data.

Professional Development and Support

Planet Earth Science does not offer professional development opportunities, but Tom Snyder Productions offers a range of seminars and workshops targeted at helping teachers to integrate educational technology into their practice. These offerings range from seminars offered at national conferences such as annual meeting of the National Science Teachers Association (NSTA) to customized workshops for schools and districts. It is important to note that these seminars and workshops are not limited to a single curriculum or program like Ocean Expeditions, although it is possible that a customized workshop could have such a focus.

The focus of the workshops reflects the approach espoused by Tom Snyder Productions, whereby technology augments effective pedagogy rather than being the focus of learning. Snyder's approach to effective pedagogy stresses using the technology to spark discussion and interaction among students and teachers. The hands-on nature of the workshops emphasizes teaching strategies as well as the use of specific technologies.

Cost and Technical Requirements

Ocean Expeditions requires a CD-ROM drive and is compatible with both Macintosh and Windows computers. A single computer license costs $99.95; a 20-

computer site license costs $799.95. For evaluation purposes, a free 45-day trial version of the program may be ordered from Tom Snyder Productions.

2.5 Modeling and simulation environments

Modeling and simulation environments make it easy for students to perform “what if” experiments or to simulate an experiment that would be dangerous or difficult to perform using real world materials. Learners typically manipulate objects in their simulations to see how they react under different conditions. For example, in modeling falling objects, where the underlying rules, such as the force of gravity, are already defined, students can compare the simulated behavior of two objects with differing masses falling in a vacuum.

Models can represent complex scientific situations like an ecosystem or the world of Newtonian physics. Students can manipulate models with a computer to make conjectures, test their ideas, and explore the rules underlying scientific phenomena. In addition to manipulating existing models, student can modify models by defining the rules that a given system, or environment, will follow. For example, they might model a simple predator/prey relationship by defining the rate at which the predator species successfully hunts its prey and the rate at which both species reproduce. Running such a model on the computer simulates how the relative populations of the two species fluctuate over time.

Many of the materials described here center around a particular simulation or modeling environment and address very specific content learning goals. In some cases, the developers of the technology believe strongly in providing such tools to teachers, who then integrate the use of the technology into their curriculum. In other cases, the developers provide a curriculum that puts the tool in context and supports the tool. In both cases, it is important to consider how the scientific understanding that the technology fosters relates to existing curricula and science standards, since virtually all of these materials are intended to be incorporated into existing courses.

BioQUEST Library

Contact information

Web site: http://www.bioquest.org/

Publisher: BioQUEST Curriculum Consortium, Biology Department, Beloit College, 700 College Street, Beloit, WI 53511.

Phone: 608/363-2743

Fax: 608/363-2052

E-mail: bioquest@beloit.edu.

Description

The BioQUEST Library is a CD-ROM that contains a collection of software-based tools, simulations, and curricular "text modules" for secondary school and undergraduate biology and life sciences education. The collection includes tools for investigating genetics and for modeling population dynamics, the human heart, and evolutionary processes. Candidates for the collection are screened using criteria that include a focus on inquiry-based science and field testing in classroom settings.

A product of the BioQUEST Curriculum Consortium—a group of researchers primarily focused on improving undergraduate biology education—the BioQUEST Library contains "more than 60 software simulations, tools, data sets, and other supporting materials in ecology, evolution, genetics, molecular biology, physiology, developmental biology, botany, and neurobiology." Many of these components are appropriate for high school students, and the BioQUEST Consortium does run professional development workshops for high school teachers.

The Library is organized into three sections:

- Programs and curricula that are being included for the first time appear in the "First Review Folder." These items have been reviewed by the BioQUEST Curriculum Consortium, but have not undergone extensive testing or refinement.
- Items in the "Collection Candidates" folder have been peer reviewed, have had at least one cycle of classroom testing and redesign, and are "complete to the point where they are fully usable in a classroom setting."
- The "BioQUEST Collection" contains materials that have had both peer review and extensive iterative testing in classroom settings. These materials have been selected by the BioQUEST Curriculum Consortium as the best, most pedagogically sound

items within the BioQUEST Library. This core collection include tools to simulate population dynamics, fruit fly genetics, human population growth, dynamic modeling of ecosystems, and the working of the heart. The core collection also includes two text modules, which are electronic documents that contain data students can use to explore evolutionary changes using off-the-shelf tools and to reflect on the pros and cons of modeling as a means of learning about scientific phenomena. Most of these materials, including all that are described above, are appropriate for high school use.

The BioQUEST group focuses on providing tools to help students engage in the practice of science, rather than on designing fixed curricular units. Teachers who adopt BioQUEST materials will need to think about how to integrate them into existing curricular materials or how to design a new curricular unit that supports the use of these instructional tools. Most of the BioQUEST workshops focus on helping teachers address this need.

Effectiveness

BioQUEST does not make available research studies evaluating the effectiveness of particular curricular materials. Lacking this information, we've included the BioQUEST Library in this review because of the screening process that the Consortium uses to evaluate new materials.

To be included on the CD-ROM, candidate materials must pass a peer review process within the Consortium to confirm that they align with BioQUEST's pedagogical philosophy for science education, which it calls the "3 P's of science education": problem posing, problem solving, and peer persuasion (cf.Jungck, 1991). This approach—which stresses the importance of engaging students in defining their own research questions, developing investigations to explore those questions, and marshalling evidence to convince others of their results—is a very good fit with national standards for scientific inquiry.

Currently, the BioQUEST Library consists of 26 "First Review Folder" items (peer reviewed by BioQUEST), five "Collection Candidates" (items that have had at least one cycle of classroom testing and redesign), and ten core modules in the "BioQUEST Collection" (extensive classroom testing). The Library is revised each year, and as materials are reviewed, they may move up from one collection to the next. New "First Review Folder" candidates also appear each year. No studies have been performed evaluating the peer review process or the classroom effectiveness of the "BioQUEST Collection."

In summary, BioQUEST's review process is designed to ensure that "BioQUEST Collection" materials support a student-driven, inquiry-oriented approach to science. The collection is a rich source of material for biology and life sciences teachers, and places an emphasis on simulation tools that allow students to explore a range of questions. The focus of the materials is primarily on software, and teachers may need to develop curriculum, or adapt existing curriculum, to put the materials in context.

Professional Development and Support

To support the use of materials on the BioQUEST CD-ROM, the Consortium runs workshops and presentations at teacher conferences, including the annual meetings of the National Science Teachers Association and the National Association of Biology Teachers. BioQUEST hosts weeklong summer workshops in Wisconsin and maintains a list of individuals in some 20 states who can serve as local workshop leaders and resources for teachers new to BioQUEST. Flannery (1996) has described her own positive experience at a BioQUEST workshop and characterized the activities and projects that occurred during the workshop.

The BioQUEST Curriculum Consortium publishes a free newsletter, *BioQUEST Notes*, that provides insights from teachers who are using BioQUEST materials in their classrooms as well as descriptions of curricula, assessments, and novel problems that are consistent with the "3 P's" approach to science education.

Costs and Technical Requirements

Site licenses for the BioQUEST CD-ROM cost $350 for high schools and high school districts; this cost can be reduced for teachers willing to field test candidate materials. For ordering information, see: www.apnet.com/bioquest/order.htm.

Teachers who are interested in the BioQUEST Library should visit www.bioquest.org to check system requirements for the packages that interest them. Most of the software on the BioQUEST CD-ROM is designed to run on Macintosh computers, and the BioQUEST Consortium is working on porting these programs to Windows. Currently, 19 simulations and tools and 10 text modules are Windows-ready. The BioQUEST Web site also provides a pointer to a program called Executor (www.ardi.com) which allows Macintosh software to run on Windows machines. Executor costs $150, with discounts for volume purchases; site licenses are available.

ChemSense

Contact information

Web site: http://chemsense.sri.com/

Address: Elaine Coleman, SRI International, 333 Ravenswood Avenue, Menlo Park, CA 94025.

Phone: 650/859-6031

Email: contact-chemsense@www.ctl.sri.com

Description

ChemSense is a learning environment designed to help high school chemistry students investigate complex chemical systems by making the underlying chemistry readily discernible and by making students' underlying thinking more evident (Schank, Coleman, Kozma, & Coppola, 1999). ChemSense is working with other developers to refine tools and connect them to the curriculum. For example, researchers from the University of Michigan contributed eChem tools (available at http://investigationstation.org/) for integration into ChemSense. ChemSense is also developing a drawing/animation studio that allows students to import molecules from eChem (and other images) to annotate and animate reactions.

The pedagogical philosophy of ChemSense is to foster inquiry by minimizing lectures and supporting groups of four to six students working around a single computer.

Effectiveness

ChemSense is conducting classroom studies in California high schools, but results are not yet available. The first set of classroom studies involved three solubility activities. Teams of four to six ChemSense members (e.g., at least one researcher, programmer, videographer, chemist) observed pairs of students do all the activities using probes and computers (PASCO, DataStudio, eChem, and a paint program). A second set of studies in a different school employed a new set of activities (involving soap), eChem, an improved whiteboard, and animation tools.

Professional Development and Support

This project is conducting studies in a few classrooms working closely with teachers. In these studies, teachers working with the leadership combine materials from eChem and PASCO with curricular materials in units such as the one on soap. In the future, these materials will be more widely available. Plans for professional development are not yet established.

Costs and Technical Requirements

Schools need to have the PASCO probes and compatible computers as well as the capability to run the software from other projects such as eChem.

Interactive Physics and Working Model Simulation Products

Contact information

Web site: http://www.krev.com/products/ip.html

Address: MSC Working Knowledge, Inc., 66 Bovet Road, Suite 200, San Mateo, CA 94402

Phone: 800/766-6615 or 650/574-7777

Fax: 650/574.7541

Description

Interactive Physics and Working Model, created by MSC Working Knowledge, Inc., provide simulation environments and libraries of prepared simulations for physics and design curricula. Developed in collaboration with educators, Interactive Physics and Working Model are based on a professional modeling tool also marketed by the company. Interactive Physics (for physics courses) and Working Model (for design courses) help students conduct controlled simulated experiments without the costs in time and materials associated with real laboratories. Students can repeat these experiments numerous times in the course of a single class period, and can readily change the values of variables and explore the parameters of experiments.

Students create models of physical systems by drawing them on the computer screen with a powerful and easy-to-use graphic interface. The model allows students to add objects like springs, dampers, ropes, and joints and to specify variables that can be measured, like velocity, acceleration, momentum, and energy. Students can interact with the simulation as it is running in real time, and they can display their measurements and parameters graphically in a variety of ways.

In addition to this open-ended modeling environment, Interactive Physics provides a library of more than 100 ready-to-run simulations, designed to meet the needs of a wide range of physics curricula. Physics teachers are encouraged to customize these basic simulations to fit their own materials and may share their customized simulations with other teachers on the "Interactive Physics Simulations Page" located on a company Web site.

Seven publishers of popular physics textbooks have adopted Interactive Physics and link Interactive Physics simulations to problems within their texts. Some of these publishers—for example, Addison-Wesley—also provide workbooks that integrate the simulations with the written exercises.

Effectiveness

Interactive Physics has been adopted by many textbook publishers, has received many awards, and is being used by thousands of teachers. The company's Web site provides links to several favorable reviews in educational periodicals and to case studies of teachers who have adopted the Interactive Physics or Working Model software.

Professional Development and Support

The company ships teacher materials with the text and CD-ROMs, but offers no ongoing support to users. The Interactive Physics Web site does provide materials, and there is one group of online teachers who seem to have self-organized.

Costs and Technical Requirements

MSC Working Knowledge, Inc., offers licensing agreements that provide CD-ROMs for schools and teachers as well as supplemental materials and even homework sets in some cases.

Interactive Physics is available for Macintosh and Windows computers. Single user license cost $279; lab packs are available and offer substantial savings by larger purchases. Interactive Physics' curriculum products cost $80 for the simulations curriculum, $45 for workbooks, and $60 for the homework edition. The homework edition is available only for Windows.

Riverdeep Interactive Learning: SimLibrary series

Contact information

Web site: http://www.riverdeep.net

Address: Riverdeep Interactive Learning, 125 Cambridge Park Drive, Cambridge, MA 02140.

Phone: 877/304-3228

Fax: 617/491-5855

E-mail: info@riverdeep.net.

Description

The primary focus of Riverdeep's science curricula is the SimLibrary series. SimLibrary is a series of courses that all build on a core simulation engine called SimPlayer. Originally published by Logal, Inc., the SimLibrary series, which includes Science Gateways and Science Explorer, is now available through Riverdeep's Web site: www.riverdeep.net.

Riverdeep has created an education "portal," a central Web site that provides a variety of links to educational material on the Internet, with information and curricula that range across social studies, math, science, and the language arts. According to Riverdeep, over 5,000 high schools use their materials in some form.

SimLibrary consists of first-year biology and chemistry courses (the Gateway series) as well as second-year biology, chemistry, and physics courses (the Explorer series). For purposes of this review, we will focus on the Gateway series, as fewer students take second year biology or chemistry classes.

The strength of the Gateway series lies in using simulations to allow students to explore, in Riverdeep's words, "phenomena that are difficult for students to understand, are time consuming or may be dangerous." Simulations also allow students to repeat experiments to explore the effects of different variables. SimLibrary simulations are designed to model a scientific investigation, where students make predictions prior to each experiment, gather data, and analyze the data in light of their original prediction.

Biological simulations in the Gateway series include population dynamics, genetics, respiration, and photosynthesis. Chemical simulations include gas laws, reaction rates, and electrochemistry. The materials also include interactive multimedia presentations, tool-based activities, and access to an online community for students.

Riverdeep provides information on its Web site linking these courses to national and state science standards, including the Sunshine State standards. The Biology Gateway and Chemistry Gateway courses are also linked to several popular biology and chemistry textbooks, with the intention that the Gateway simulations may be used to augment existing curriculum.

Effectiveness

Riverdeep does not cite any research studies that relate directly to the SimLibrary products. The Explorer series has won some software industry awards, including the 1998 EDDIE award from the ComputED Learning Lab in Cardiff, California. This award recognizes innovative educational software based on "academic content, potential for broad classroom use, technical merit, subject approach, and quality of management system." ComputED Learning Lab itself selects the award winners.

Professional Development and Support

Riverdeep offers several online courses that are intended to help teachers integrate the use of simulations into their classrooms. These courses range from short step-by-step tutorials that familiarize teachers with the technology to more in-depth, graduate credit courses that relate the use of simulations to innovative assessment methods and pedagogy. Riverdeep also offers week-long summer institutes throughout the country that help teachers learn to use simulation tools in the classroom.

Riverdeep also provides support for an online educators' community that includes discussion forums, a monthly newsletter, lesson plans, and assessment ideas.

Cost and Technical Requirements

All SimLibrary-related curricula are available for Macintosh and Windows computers:

Windows: 486 or higher, Windows 95/98 or NT 16, Mb RAM, QuickTime 32-bit, Sound Capabilities CD ROM.

Macintosh or PowerMac: System 7.1 or higher, 16 Mb RAM, QuickTime 2.5 or higher, Sound Manager 3.2, CD-ROM.

Access to the Riverdeep Web site depends on having suitable Internet access. Free 90-day subscriptions are available for educators who wish to review Riverdeep's course materials and titles.

Individual courses such a Biology Gateways or Physics Explorer are available for $475. These courses may also be purchased in volume by school districts for $200 per course taught. Alternatively, schools may pay a subscription fee of $5 per student to gain access to the entire Riverdeep collection of courses and titles for one year.

Stagecast Creator

Contact information

Web site: http://www.stagecast.com/

Address: Stagecast Software, Inc., 580 College Avenue, Palo Alto, CA 94306

Phone: 877/STAGECAST

Fax: 650/354-0739

E-mail: info@stagecast.com.

Description

Stagecast Creator is a software package that allows students to assign attributes and behaviors to a series of online characters or agents. The software can be used to model a variety of scientific phenomena. Stagecast provides a collection of sample models that teachers can use as starting points for curriculum development.

Stagecast Creator is related to an earlier software environment called Cocoa, and is similar to another program called AgentSheets (www.agentsheets.com). All of these environments allow the user to control the behavior of agents that move on a two-dimensional grid. For example, students might model a plant's growth process. To do this, they create a "world" that is several grid cells wide and several cells tall. They also create several kinds of cells: ground, clouds, rain, seeds, and plant. Each of these cells has a certain set of behaviors, which the students control. For example, clouds may move horizontally across the world (in the sky), and periodically release rain. Rain cells fall straight down until they hit the ground. If rain hits the ground where there are seeds, a plant cell appears. By defining different kinds of cells and specifying behaviors and relationships among the cells, students can see what happens over time. The challenge for students is to specify the behavior of individual agents in sufficient detail to model the behavior of the overall system.

Stagecast provides a lesson plan matrix showing how the activities that ship with Creator relate to grade level and discipline. Most of these pre-designed activities have been designed for younger ages and are too simplistic for high school science topics; however, it is worth examining them as starting points for encouraging students to design their own models.

Effectiveness

There are efforts underway to study the role of modeling environments like Stagecraft Creator in classrooms, but none has produced definitive results.

Two research efforts relate to the potential impact of Creator in the classroom. The first is work on constructionist learning environments by researchers such as Resnick and Repenning (Repenning, Ioannidou, & Phillips, 1999; Resnick, Berg, & Eisenberg, 2000). Constructionism extends some of the ideas behind constructivist learning by placing students in environments in which they construct physical objects such as models. Resnick's work with StarLOGO, a parallel processing version of the LOGO graphical programming language, has some similarity to Creator in that students specified the behavior of individual agents, placed the agents within a world and observed what happened over time (Resnick, 1996). In his study, Resnick worked with small groups of students who were able to design dynamic systems that display complex behavior, such as traffic jams, even though the systems were based on very simple rules. Resnick's work established the promise of dynamic modeling environments like StarLOGO and Creator to allow students to learning about complex scientific ideas by modeling them.

The second effort is a report for the Educational Testing Service on the relationship of educational technology and student achievement in mathematics (Wenglinsky, 1998). The report draws on data from the 1996 National Assessment of Educational Progress to argue that certain uses of computers, including the use of simulations, were associated with improved academic performance and school climate. At the eighth grade level, the closest grade level to high school in the study, researchers found that using computers to teach higher order thinking skills was associated with an improvement in academic performance and school climate. Stagecast cites this report on their Web site. Although the report was not based on studies of Creator in the classroom and did not suggest that Creator would contribute to teaching higher order thinking skills, it does raise the possibility that using Creator for model-building activities could engage students in higher order thinking and problem solving.

Professional Development and Support

Stagecast provides a limited set of resources to support teacher professional development. The company provides technical support and an online tutorial for its software. Stagecast also hosts an online discussion group through which teachers can ask questions and share ideas with other teachers using Creator.

Costs and Technical Requirements

Creator is available for both Macintosh and Windows platforms. Minimum system configurations are Windows 95 and MacOS 7.6.1, and the program does require at least 20M of free RAM.

The education edition of Creator costs $89.95, with five-user packs available for $229.95 and 25-user packs available for $775.00. A free evaluation version may be downloaded from the Stagecast Web site. The evaluation version has an expiration date and limits the complexity of the worlds that the user can create.

STELLA

Contact information

Web site: http://www.hps-inc.com/

Address: High Performance Systems, Inc., 45 Lyme Road, Suite 300, Hanover, NH 03755.

Email: webmaster@hps-inc.com.

A great deal of curriculum for use with STELLA is also available through the Creative Learning Exchange (CLE) Web site at sysdyn.mit.edu/cle/.

Description

STELLA (Structural Thinking Experimental Learning Laboratory with Animation) is a professional systems modeling application that can be used in a variety of science contexts. Using STELLA, students can model the behavior of complex, dynamic systems over time. An example of a dynamic system is the relationship between predator and prey species. By modifying the rates of reproduction, predation, and death due to old age or starvation, students can see how the population levels of the two species are related and move through boom and bust cycles over time.

High Performance Systems, the makers of STELLA, provides support for the software and has designed specific learning environments for high school teachers to use with STELLA. For example, the *Fly A Cell* environment asks students to determine what is causing a cell to die and has them choose which proteins to produce to defend the cell from toxins.

Students can also use STELLA directly to model systems and behaviors in a wide range of domains; typical examples include ecosystem modeling (e.g. tracing pollution levels in streams or lakes), Newtonian mechanics, and chemical reactions. (STELLA has even been used to model historical events and psychological experiments.)

Mandinach and Cline (1994) discuss the range of ways in which students and teachers may use STELLA. At one extreme, students interact with a pre-existing model, created by the teacher or a curriculum developer. Students run the model, observe the results, and draw conclusions based on the data. A more interactive use of the software lets students manipulate parameters in the model, such as the birthrate of deer in a population model or the force of gravity in a physics model, to see how these factors affect other properties in the model.

Students can also create and refine their own models to better understand some real world system — for example, modeling the inflow and dispersion of industrial chemicals into an estuary. Students identify the system's most important variables and relationships and then manipulate the parameters of the model to see what happens as the circumstances change.

Published curricula that use STELLA are rare. Science and Sustainability, described elsewhere in this review, incorporates STELLA in some of its curricular activities. Teachers interested in learning more about STELLA in a structured context may wish to examine this connection.

The Creative Learning Exchange (sysdyn.mit.edu/cle/) is an independent organization that provides links to a collection of online materials; these tend to be individual activities submitted by teachers, rather than a curricular sequence, and are not tied to specific science standards.

Effectiveness

The primary study of the use of STELLA in high school classrooms was the STACI^{N} project, which involved nearly 100 Vermont high school teachers and 6,000 students over an eight-year period. The STACI^{N} project was an experiment in using systems dynamics and STELLA to "examine the impact of systems thinking, simulation, and modeling in pre-college curricula on student learning, classroom processes, and organizational change." (Mandinach & Cline, 1994). The focus was not on evaluating a specific curriculum that used STELLA but rather on seeing what would happen if teachers were trained in systems dynamics and integrated STELLA into their own curricula. The project provided computers, training, a stipend, and ongoing support for participating teachers. Over the course of the project, as teachers grew more familiar with the technology, more and more workshop time was spent working with teachers to create curricula. The results of this study suggest that teachers must invest substantial time and energy to reach a point at which they can effectively integrate STELLA into their curriculum; however, once that investment is made, the software is well suited to the kinds of authentic learning that are the focus of this review.

Systems dynamics as a domain is broad enough to address virtually any science domain standard, as models of the target domain can be built within the software environment. However, teachers must be willing either to develop their own curriculum or to explore existing curricular offerings, which are fairly scattered and are not connected to specific standards.

Mandinach and Cline also described how teachers adapted their practice so as to use STELLA in innovative, learner-directed ways. They described a developmental progression from simple survival, in which teachers learned about the software and what might constitute appropriate use of the technology, through mastery, to innovation, where teachers employed the technology within a constructivist setting. Although their longitudinal results do not allow them to comment on individual teachers, the results do indicate that, as teachers develop proficiency with the technology, their practice also changes to accommodate more inquiry-based, student-directed activities.

Professional Development and Support

High Performance Systems offers technical support for STELLA as well as an annual summer workshop for teachers interested in using STELLA in the classroom. Details about the workshop are available on the HPS web site (www.hps-inc.com). Workshop costs are $900 for the first participant and $450 for additional participants from the same school. HPS also offers workshops for the "sister" program to STELLA, iThink, which is geared towards business applications. According to HPS, it is not uncommon for teachers to attend iThink workshops, since the dynamic modeling principles behind the two software packages are very similar.

The Creative Learning Exchange (CLE) maintains an independent Web site that offers a centralized resource for teachers interested in STELLA and systems dynamics. The site (sysdyn.mit.edu/cle/) includes pointers to teacher-developed curricula, a free newsletter, and a lively email listserv (sysdyn.mit.edu/k-12sd-email-list/home.html) that allows teachers to share ideas and ask questions about using STELLA in the classroom. According to HPS, the listserv is one of the best resources available for teachers planning to use STELLA. CLE also organizes a yearly conference for teachers interested in systems dynamics and modeling. See CLE's Web site for details.

Costs and Technical Resources

STELLA costs $300 and runs on both Windows and Macintosh platforms. Customized learning environments such as Fly A Cell, which use a runtime version of STELLA but essentially limit students to working on the problem posed in the learning environment, are available for $99. For teachers who are interested in learning more about STELLA, HPS has a downloadable demo that includes sample models in various domains.

2.6 Probeware and data collection

An important technological support for science learning, probeware refers to a variety of sensors that connect to a computer, calculator, or handheld PDA and allow students to record data about their environment in real time. Common probe types include temperature, voltage, and motion sensors. The Concord Consortium provides an excellent introduction to probes online at http://www.concord.org/probesight/.

The use of probes in calculator-based labs (CBL) and microcomputer-based labs (MBL) has been studied for well over a decade. The chief advantages that probes provide is real-time graphing, which enables students to view scientific phenomena in a completely new way (Krajcik & Layman, 1993; Mokros & Tinker, 1987). Using various software packages, students can see immediately how, for example, the temperature of water in a heated beaker changes over time. The use of probes in an inquiry environment has been shown to help students to distinguish between important scientific concepts such as heat and temperature (Linn & Hsi, 2000). Probes can be programmed to take readings at fixed time intervals, enabling students to measure very slow changes as well as quick ones. For example, a temperature probe can be used to measure the change of temperature of concrete as it sets overnight, demonstrating that this process is exothermic.

Probes, although more expensive initially, compare favorably to consumable lab supplies over the long term, because they are re-usable and allow students to take measurements as often as they want. Since probes can be connected to computers and calculators, they offer the possibility of integrating real-time data collection into other curricular activities. For example, teachers and students working with project GLOBE (reviewed in this document) use probes to collect data that is shared with other students around the world.

In this section we will describe the two companies who provide hardware, software, and curricula to support the use of probes. We will focus on vendors who provide support and technology for three distinct platforms: calculator-based environments (CBLs), personal computer-based environments (MBLs), and hand-held platforms such as the Palm III or the Handspring Visor. Note that there are other companies, including

PASCO (www.pasco.com) and Team Labs (www.teamlabs.com), which provide similar packages for MBL environments.

CBLs and MBLs: Vernier Software

Contact information

Web site: http://www.vernier.com/

Address: Vernier Software & Technology, 13979 S. W. Millikan Way, Beaverton, OR 97005-2886

Phone: 503/277-2299

Fax 503/277-2440

E-mail: info@vernier.com.

Description

Vernier makes a wide range of probes as well as software and interface boxes that allow these probes to be used with CBLs and MBLs. Vernier's CBL interfaces are compatible with most recent Texas Instruments graphing calculators, and graphs of the data can be display in real time on the TIs. For MBLs, Vernier's LoggerPro software, compatible with Windows and Macintosh computers, provides graphing and data analysis capabilities.

Curricular offerings for both CBL and MBL environments are also available, and Vernier provides connections to national science standards for its core curricular offerings in biology, chemistry, physics, physical science, and water quality. Vernier's curricular materials for biology, chemistry, and physics are intended to support, rather than replace, the curriculum a teacher is already using. For example, the chemistry curriculum includes 31 experiments, each of which serves to illustrate a particular principle, such as Boyle's Law. It is important to note that these curricular offerings alone do not provide an authentic context for science learning, as many of the labs involve standard experimental equipment and are not put into the context of the course being offered or tied to real world phenomena.

Despite these limitations, using real-time graphing and probes has great promise. Probe technology provides students with a new way to understand scientific principles and can support student inquiry very effectively, when used in appropriate settings. Vernier's water quality curriculum comes closer to achieving this goal, since it presumes a driving question—evaluating water quality—that provides an overarching framework for understanding the results of individual tests.

Effectiveness

Vernier does not cite specific research to support the use of its probes or curriculum. However, Vernier probes have been used in related research projects, including GLOBE, as well as in the case studies reported by ImagiWorks. Many of the benefits associated with past research on probing and real-time graphing may apply to the use of Vernier's products, with the caveat mentioned above: that many of the curricular activities provided by Vernier are intended to be stand-alone lab activities and are not designed to encourage students to investigate their own questions or relate their findings to their own experience.

Professional Development and Support

Vernier attends most science education conferences and runs a variety of workshops around the country, including workshops run by local affiliates that focus on technology training with CBL and MBL equipment and hands-on evaluation workshops that focus on helping teachers to integrate probes into their classrooms. A calendar of upcoming workshops and conference appearances is available on Vernier's Web site.

Costs and Technical Requirements

Vernier sells comprehensive starter packs for MBLs that includes software, one interface box, an activity book, and 16 different probes for about $1,300. A deluxe starter pack for chemistry, which includes the interface box, software, and six probes, costs $500. Probes and equipment may also be purchased individually. Vernier's MBL interface is compatible with Macintosh and Windows computers. Vernier's CBL interface, which costs $179, requires a recent Texas Instruments calculator. Probes and curricula may be purchased separately. Probes range in cost from $50 to $300, depending on the particular sensor.

Handhelds: ImagiWorks

Contact information

Web site: http://www.imagiworks.com

Address: ImagiWorks, Inc., 60 East 3rd Street, Suite 230, San Mateo, CA 94401

Phone: 650/373-0300

Fax 650/373-0301

E-mail: info@imagiworks.com.

Description

ImagiWorks sells ImagiProbe, an interface box and software that allows students to collect real-time data using handheld devices like Palm Computing products and the Handspring Visor. ImagiProbe is compatible with standard probes from Vernier and other companies.

By using a handheld instead of a desktop computer, students are able to carry a compact real-time testing kit with them, instead of being tethered to a lab table or a desk. This portability is similar to that of CBLs. ImagiWorks also sells a small spreadsheet application that runs on hand-held devices. This program, called QuickSheets, accepts data from ImagiProbe and allows students to perform analyses at the testing site.

Effectiveness

ImagiWorks cites two “success stories” in which students have taken Palm computers and ImagiProbes outside and used them to test for water quality in local streams. These case studies describe some of the challenges faced in training students to use the software, and they argue that the use of hand-held devices and probes frees students to engage in inquiry learning outside of the traditional science classroom.

Professional Development and Support

ImagiWorks is beginning to offer a series of training events for teachers to learn about using probes and supporting student inquiry with probes. The workshops are currently in the planning stage. Contact ImagiWorks directly for more information.

Costs and Technical Requirements

The ImagiProbe package, which includes software and one interface for a handheld computer, costs about $300. Note that this price does not include the cost of probes (see entry for Vernier for representative prices on probes) or the cost of the hand-held device itself (about $150).

A water quality package, which includes ImagiProbe, dissolved oxygen, pH, and temperature probes, and a set of curricular activities related to water quality, is available for $600. A general science package, which includes a set of curricular activities and light, voltage, and temperature probes, is $430.

Probe-based Physics

Contact information

Web site: http://www.teamlabs.com/physbk.html

Phone: 877/TEAMLABs (877/832-6522)

Fax: 303/541-9141

Email: webmaster@teamlabs.com

Description

Probe-based Physics features 40 activities for high school courses that use Team Labs probeware systems or associated products. The experiments are organized in four topic areas: Time, Distance, Speed and Acceleration; Forces; Energy, Power, and Momentum; Heat, Light, and Electricity. The activities have both student and teacher sections with sample data and calculations.

Effectiveness

Considerable research demonstrates the value of probe-based experiments in science class (Krajcik & Layman, 1993; Mokros & Tinker, 1987). Students learn more about graphing with well-designed real -time data collection experiments than they do from hand drawn graphs (Linn & Hsi, 2000).

Professional Development and Support

PSL offers three options:

- Team Labs' on-site training: Cost is per day with one day of travel required, as well as expenses for hotel and airfare. Recommended two-day training minimum. Class size should not exceed 15 people.
- Certified "Technology Educators" from Team Labs: Independent education professionals including many former science teachers who have extensive knowledge of PSL and other products which teachers may want to incorporate into their curriculum.
- Team Labs Training in Boulder, Colorado: Team Labs offers comprehensive three-day staff development for customers or for anyone else who wishes to become a certified Technology Educator. These classes are held periodically throughout the school year and during the summer in Boulder, Colorado. The next sessions will be held in summer 2000, June 19-20 and June 22-23.

Costs and Technical Requirements

The probeware only is available for $1,459. A basic package, which includes probeware, software, and the Probe-based Physics Curriculum Book, costs $ 1,717.

3. Recommendations for technology-based science instruction

3.1 Overview

In this section we will:

- explain how our pedagogical criteria and The Seven Dimensions of Progress can be synthesized in three realms that are essential to improving instruction: promoting science understanding, amplifying teacher effectiveness, and enabling customization
- identify the six programs that best reflect these principles, and use them to illustrate how technology and pedagogy contribute to authentic, inquiry-based science learning
- discuss briefly the role of technology in science education, and suggest that teachers use the criteria we have proposed in this report to evaluate the programs and technologies that emerge over the next several years.

Our criteria and Milken's Seven Dimensions offer complementary perspectives on science education. Our criteria focus on pedagogical soundness and classroom-based research, and they serve primarily to identify programs that have great promise for classroom use; however, it is equally important to develop support for evaluating and adapting curricular materials once they are introduced. The Seven Dimensions offer a model for evaluating curricular programs *in context*. By considering the relationship of the district, its technological capacity, the teachers, students, community, and parents, the Seven Dimensions provide a broad contextual framework for assessing and refining programs. Our view is that both sets of measures, our pedagogical criteria and the Seven Dimensions, can help educators select effective programs and refine them as needed to best match the context of their classrooms and schools.

Table 3.1 illustrates how our pedagogical criteria relate to the Seven Dimensions in three broad categories that are critical for successful science instruction: promoting science understanding, amplifying teacher effectiveness, and enabling customization.

Table 3.1 Synthesis of Our Pedagogical Screening Criteria and The Seven Dimensions of Progress

Pedagogical screening criteria	*Seven Dimensions of Progress*
Promoting Science Understanding	
· Connects to personal, relevant, or authentic experiences. · Encourages links to other topics in science · Supports peer learning · Promotes autonomous inquiry · Enables lifelong learning and revisiting of ideas	1. LEARNERS *Are students using technology in ways that deepen their understanding of academic content and advance their knowledge of the world around them?* 2. LEARNING ENVIRONMENTS *Is the learning environment designed to achieve high academic performance by students?* 7. ACCOUNTABILITY *Is there agreement on what success with technology looks like? Are there measures in place to track progress and report results?*
Amplifying Teacher Effectiveness	
· Uses technology to enhance understanding	3. PROFESSIONAL COMPETENCY *Are educators fluent with technology and do they effectively use technology to the learning advantage of students?* 5. COMMUNITY CONNECTIONS *Is the school-community relationship one of trust and respect, and is this translating into beneficial, sustainable partnerships in learning technology?* 6. TECHNOLOGY CAPACITY *Are there adequate technologies, networks, electronic resources and support to reach the education systems learning goals?* 7. ACCOUNTABILITY
Enabling Customization	
· Meets diverse student needs (and has been or can be tested with these populations).	3. PROFESSIONAL COMPETENCY 4. SYSTEM CAPACITY *Is the entire education system reengineering itself to meet the needs of students in this knowledge-based, global society?* 7. ACCOUNTABILITY

3.2 Recommended programs

We selected six programs in a variety of disciplines that meet the criteria articulated above. These programs reflect our focus on technology-rich *curricula* as opposed to technological tools.

Among comprehensive curricula, two full-year programs stood out. Constructing Physics Understanding (CPU) and Science and Sustainability (S&S) both provide substantial opportunities for using technology to support authentic learning activities. CPU provides an innovative replacement for a standard physics course, while S&S offers its own curriculum, designed around the theme of sustainable living, that covers science content in a variety of disciplines.

Also of note is the Virtual High School project, which uses technology to make a rich array of courses available to schools around the country.

Two learning environments, WISE and WorldWatcher, make innovative use of technology to support student investigations. Both programs support the process of student inquiry and provide tools for exploring specific phenomena.

Finally, Project GLOBE supports synchronized collaborative courses in earth sciences. The GLOBE technology contributes to communication between distant classrooms, and it supports data collection and analysis. GLOBE's targeted science content, which emphasizes regional variation, is well suited to such synchronized curricula.

In addition to these six programs, we strongly recommend that teachers consider the use of real-time probes (probeware) and simulations to support existing or new curricula. Although many of the materials we reviewed in these domains lacked the pedagogical context we were seeking, these technologies have exceptional promise for teachers willing to integrate them into authentic learning settings.

3.3 Promoting science understanding

To help students understand science better, programs must support them as they analyze, compare, organize, and sort out new and familiar ideas. Five of our pedagogical criteria address the process by which students come to understand scientific concepts. These criteria call for programs that build on what students know, connect to related topics, take advantage of peer learning, provide opportunities for independent work, and prepare them to revisit their ideas once science class is over. Two of the Seven Dimensions also relate to science understanding and stress the importance of the environment in which learning occurs.

Current educational research suggests that effective instruction can promote science understanding by strengthening students' interest in and ability to link, compare, critique, and sort out conflicting scientific ideas (Linn, diSessa, Pea, & Songer, 1994; Linn & Hsi, 2000). Curricular materials can support this process. Classroom activities can encourage students to revisit their ideas and to reflect on their own progress. Group projects and discussions can enable students to learn from their peers. The combination of building on one's own ideas, sorting out alternatives, reflecting on one's own progress, and consulting with peers is characteristic of successful science instruction.

Many recent instructional development efforts have incorporated current educational research to improve students' understanding of scientific concepts by building on the ideas that they have when they enter the classroom. For example, some projects provide teachers with a compendium of "common ideas" held by entering students, assessments that make students' thinking evident, or benchmark lessons that draw out students' ideas and encourage them to reflect upon and discuss these ideas and their implications. Constructing Physics Understanding identifies common ideas that students bring to science class and provides activities designed to connect normative views of physics to the students' intuitive ideas. In a similar vein, the WorldWatcher project has engaged in years of research examining how students interact with scientific visualization software. This work has informed the design of its technology and its curriculum. The project currently provides several means by which students can express their own ideas visually.

The pedagogical literature heralds peer learning as another way to improve instruction. Technological support for peer learning can include collaborative discussion tools, visual representations of ideas, and data that can be shared across time and distance.

Many researchers have built stand-alone tools to encourage online, asynchronous discussion. These tools can be incorporated into most instruction. However, as stand-alone tools, they demand substantial contributions from users to be effective. Discussions are more successful when students are encouraged to address specific complex problems together and to consider, and evaluate, the solutions suggested by their peers (Hsi & Hoadley, 1997). All of the programs recommended here encourage peer learning, and most provide specific technological support for peer learning. For example, WISE uses online discussions to enable students to learn from each other and help each other understand complex scientific questions. GLOBE and WorldWatcher both allow students to share data; in addition, GLOBE provides the means for students to interact with experts who can respond to their ideas and questions and help them interpret data. Virtual High School depends on online discussion tools, along with email, to allow teachers to interact with students and to support student collaboration in online courses.

Pedagogical research underscores the importance of instructional materials that help students document, organize, synthesize, and critique their ideas (Davis, 1998; Edelson et al., 1999; Loh et al., in press; Slotta & Linn, 2000). Many of our recommended programs provide support—often technological support—for making sense of science and for making students' thinking visible. For example, WISE provides students with SenseMaker, a tool for visually arranging evidence to support or refute specific hypotheses or theories. Science and Sustainability (through its partnership with the Progress Portfolio project) and WorldWatcher (through its own online journaling tool) provide software that lets students capture and annotate evidence as they progress through an investigation. Tools like these are important, because they enable students to make predictions, easily capture scientific evidence, and document their findings in computer-based investigations. As more and more technology-based curricula emerge, these tools for organizing and documenting scientific ideas will become more and more valuable.

Technological tools that support scientific visualization and clarify complex relationships are also a boon to science instruction. Visualization tools, simulation and modeling tools, and real-time probeware are all examples of technologies that allow students to see and manipulate scientific phenomena in new ways. For example, Constructing Physics Understanding incorporates many powerful simulations into a curriculum or activities. Many of these technologies are complex; users may need training to adapt them so that they function effectively in the classroom. WorldWatcher has addressed head-on the challenges of adapting scientific visualization tools for classroom use (Edelson et al., 1999); it is an outstanding example of designing a curriculum to take best advantage of a particular visualization tool. GLOBE also offers a variety of data display tools that students can use in their investigations.

Research has long documented the power of probes for helping students make sense of science through data collection and real-time graphing (Linn & Hsi, 2000; Mokros & Tinker, 1987). In addition to the probe-specific curricula from Vernier and ImagiWorks, several of our recommended curricula have projects or activities that can incorporate probes. For example, WISE and GLOBE both have activities that support probe use. Probes are not required for Science & Sustainability activities, but, where appropriate, their use is encouraged. Because probes can be used to support many different kinds of activities (e.g. using a temperature probe wherever a thermometer is needed), we recommend that, rather than adopting probe-specific curricula, teachers integrate the use of probes into their existing science curriculum.

3.4 Amplifying Teacher Effectiveness

Technology does not and should not replace the teacher in the classroom: its role is to *amplify* the teacher's ability to support student learning. How can teachers who introduce innovative programs exploit technology most effectively? They can use technological tools to help them shed the traditional role of "sage on a stage" and become instead a "guide on the side" for authentic, inquiry-based learning.

Information technology provides access to people, ideas, and resources that can help teachers anticipate their students' needs and guide their investigations. Often a mentor or an online professional development group can proffer just the advice a teacher needs to make an inquiry activity succeed.

Technology can also amplify a teacher's effectiveness by reducing the logistical constraints associated with inquiry instruction. For example, computer learning environments can handle logistical details, prompt students to reflect, and guide inquiry. These features can free teachers to spend more time working with students, understanding the ideas that students bring to science class, testing classroom activities to promote understanding, and redesigning courses. The WISE project offers a wide range of inquiry supports, including online hints that help students procedurally and conceptually and an inquiry map that reminds students where they are and what they need to do next. WISE also provides classroom management and assessment support that simplifies the work a teacher has to do when preparing a computer-based activity or collating computer-based student work for grading. Virtual High School provides tools that help teachers do classroom management and assessment online.

While many programs seek to familiarize teachers with their technology through professional development, it is difficult to determine how effective these opportunities are, because they typically vary a great deal from session to session. More research on professional development support issues is needed; however, based on what we know, we can propose criteria for professional development opportunities:

First, professional development should address the pedagogical goals as well as the technological aspects of the program. We believe that successful programs will use the same pedagogical approach for teachers that they do for students. Both WISE and the Virtual High School offer online courses that address pedagogical issues. In the case of VHS, teachers cannot teach online courses until they have taken an online seminar on teaching virtual courses themselves. Science and Sustainability also offers summer institutes that stress their issues-oriented instructional approach.

Second, the training should provide on-going access to people—beyond the duration of the in-service workshop or summer institute. Many of the programs reviewed here provide e-mail lists that allow teachers to remain in contact with their peers and the program directors throughout the academic year. WISE and the Virtual High School both provide online community spaces for teachers on their own Web sites. Science and Sustainability provides similar support through TAPPED-IN, a large online teacher community project. These projects all build on the sense of community that develops during in-service or summer workshops. They also encourage teachers to be part of a collaborative group that jointly tests and refines classroom materials.

We strongly recommend that teachers who are introducing new curricula seek support through a professional development program that meets these criteria.

3.5 Enabling Customization

While our selection criteria have been based on pedagogical soundness and classroom-based research, even programs that meet these criteria may need to be adapted for use in new settings. We consider customization—the act of adapting a curriculum to match the needs and constraints of specific classroom settings—to be a critical part of successful science instruction.

Curricular materials vary in their ability to support teachers and enhance student learning. Those that can be easily modified are generally more effective. When materials for a science curriculum are designed so that they can be readily customized, teachers can develop instruction suited to the student population, the course goals, and their personal strengths. Some science curriculum materials permit instructors to make design refinements and even to carry out classroom experiments to determine which approaches are most successful with particular students.

When science curriculum materials are easy to modify, teachers can link them more effectively to prior courses and to courses that will follow. Furthermore, when this tailoring and customizing occurs in a technological learning environment, the refined version of the curriculum can be maintained electronically and updated for use in subsequent semesters. Electronic learning environments enable teachers to take a more cumulative approach to instructional design than is often possible with other curricular materials.

We recommend a process of iterative curricular refinement, in which teachers enter into partnerships with their colleagues and others (discipline, pedagogy, and technology specialists) to pilot test the curriculum, observe each other teaching, and identify productive customizations of the curriculum that take advantage of specific geographic location, school features, student backgrounds, and teacher talents (Linn, Shear, Bell, & Slotta, 1999). Many of the technologies that support teacher communities and ongoing professional development may be employed to help support these efforts.

Today only a handful of materials permit the sort of customization that would empower teachers to refine their courses in a cumulative manner. Of the programs we selected, WISE offers the greatest degree of flexibility, and uses technology to allow teachers to modify curricula directly. For example, teachers in a Russian bilingual class added special glossary pages to assist language learners in interpreting material about frog deformities. Using WISE, it would also be possible to customize a basic water quality project so that students could explore the potential impact of local industry or agriculture on the environmental characteristics of a local stream.

Other programs also employ customization. In the GLOBE project, teachers can adapt the climate measurement activities to issues that are relevant to students in their locale; they can also hold discussions with students in remote regions to explore the differences. WorldWatcher allows teachers to create customized online worksheets that include hyperlinks to specific visualizations and data sets. Virtual High School provides online tools that teachers can use to design and refine courses.

SEPUP, the developer of Science and Sustainability, supports customization on a larger scale. If a district wants to adopt SEPUP materials but needs the materials adapted in particular ways, SEPUP will work with the district to design a customized version of the curriculum for use in the district.

While our recommendations have focused primarily on curricular products rather than stand-alone tools, it is worth noting that many designers of software tools, including the BioQUEST Curriculum Consortium, argue that providing teachers with powerful inquiry tools contributes to instructional reform (Jungck, 1991), because the tools can be used in a variety of contexts and may be more easily adapted into existing curricula. BioQUEST is a good example of a case in which the tools are consistent with an inquiry-oriented approach to pedagogy; in addition, its professional development efforts center on integrating the tools into an existing or a new curriculum.

3.6 Summary: The role of technology in science education

Programs that integrate technology into science instruction most successfully promote science understanding, amplify teacher effectiveness, and enable teachers to customize courses and activities for diverse classroom settings. The six programs we have described here all address these important goals, although they do so in very different ways:

- Constructing Physics Understanding and Science and Sustainability come closest to the traditional model of a yearlong comprehensive curriculum. Both programs make innovative use of technology to support an authentic, inquiry-based approach to learning science.
- WISE and Virtual High School demonstrate the potential of online science learning. While WISE uses shorter curricular units and provides substantial support for student investigations, VHS focuses on making new science courses available to schools that could not offer these courses in any other way.
- GLOBE and WorldWatcher represent programs that use technology to support student interpretation of data that relates to the world around them.

We encourage teachers to browse through our complete list of programs and tools, since each entry contributes to effective science instruction in its own way.

As we all know, the current pace of technological innovation is truly breathtaking. New technologies and new programs that take advantage of these technologies will continue to emerge over the next several years. Even in the course of this review, new programs have appeared, and older programs have ceased to provide support or have reappeared with new names or new distributors. This pace of change makes it extremely challenging to conduct a comprehensive review of all technology-supported science curricula, and we do not present this work as comprehensive. Rather, the programs in this review are a cross-section of the curricular materials and tools that we found at one point in time.

Given the pace of technological change, we urge teachers to use the criteria enunciated here to evaluate new technologies and technology-rich curricula as they emerge. How well do new programs support science understanding? Do new technologies offer innovative ways to view science, as we have seen with real-time probes? What assumptions do new programs make about science pedagogy? What kinds of professional development support and teacher community do they provide? Questions like these can help teachers, administrators, and parents learn how new technologies and programs can contribute to effective science instruction and how they can customize these programs to meet students' needs.

4. References

AAAS. (1993). *Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., Bransford, J. D., & The Cognition and Technology Group at Vanderbilt. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences, 7*(3 & 4), 271-312.

Baumgartner, E., & Reiser, B. J. (1997). Inquiry through Design: Situating and supporting inquiry through design projects in high school science classrooms. In Annual Meeting of the National Association for Research in Science Teaching (Ed.), *Oak Brook, Illinois* .

Berenfeld, B. (1994). Technology and the new model of science education: The Global Lab experience. *Machine-Mediated Learning, 4*(2/3), 203-227.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1992). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 27*, 369-398.

Boone, G. (1998). Task Force: Environmental investigation kit. *The American Biology Teacher*, *60*(4).

Borst, R. (1997). Classroom air quality: Exploring the indoor environment. *Clearing 98*, 14-15.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, Mind, Experience, and School*. Washington, DC: National Research Council.

Brown, M., & Edelson, D. C. (1999). A lab by any other name: Integrating traditional labs and computer supported collaborative science investigations. In C. Hoadley (Ed.), *Proceedings of Computer Supported Collaborative Learning 1999* (pp. 73-80). Palo Alto, CA.

Committee on Information Technology Literacy. (1999). *Being fluent with information technology*. Washington, DC: National Research Council.

Cuban, L. (1986). *Teachers and machines: the classroom use of technology since 1920*. New York: Teachers College Press.

Davis, E. A. (1998). *Scaffolding students' reflection for science learning.* Unpublished Unpublished doctoral dissertation, University of California, Berkeley, CA.

Edelson, D. C., Gordin, D. N., & Pea, R. D. (1999). Addressing the challenges of inquiry-based learning through technology and curriculum design. *Journal of the Learning Sciences, 8*(3/4), 391-450.

Espinoza, C., Dove, T., Zucker, A., & Kozma, R. (1999). *An evaluation of the Virtual High School after two years of operation* . Menlo Park, CA: SRI International.

Flannery, M. C. (1996). Making biology problematic. *American Biology Teacher, 58*(8), 499-502.

Garcia, E. (1998). Salmon conflict. *The Science Teacher*, *65*(2), 72.

Gerace, W., Dufresne, R., Leonard, W., & Mestre, J. (1999). *Minds-on Physics: Materials for developing concept-based problem-solving skills in physics*. University of Massachusetts. Available: http:// www-perg.phast.umass.edu/outreach/MindsOnPhysics/.

Gordin, D. N., & Pea, R. D. (1995). Prospects for scientific visualization as an educational technology. *Journal of the Learning Sciences, 4*(3), 249-279.

Hsi, S. (1999). *Fostering effective instruction in a Virtual High School: A NetCourse for teachers.* Paper presented at the Annual Meeting of the American Educational Research Association, Montreal, Canada.

Hsi, S., & Hoadley, C. M. (1997). Productive discussion in science: Gender equity through electronic discourse. *Journal of Science Education and Technology*, *6*(1), 23–36.

Hsi, S., & Tinker, R. (1997). *A scalable model of collaborative learning: The Virtual High School Cooperative.* Paper presented at the International Conference on Computer-supported Collaborative Learning, OISE, Toronto.

Jungck, J. R. (1991). Constructivism, computer exploratoriums, and collaborative learning: Constructing scientific knowledge. *Teaching Education, 3*(2), 151-170.

Kelly, P. J. (1991). *Perceptions and performance: An impact assessment study of CEPUP in schools* . Berkeley, CA: Science Education for Public Understanding Program.

Koker, M. (1992a). *SEPUP in Cleveland: An impact study of SEPUP on teachers and students* . Berkeley, CA: Science Education for Public Understanding Program.

Koker, M. (1992b). *SEPUP in Philadelphia: An impact study of SEPUP on teachers and students* . Berkeley, CA: Science Education for Public Understanding Program.

Koker, M. (1996). *Students' decisions about environmental issues and problems: An evaluation study of the SEPUP program.* Unpublished Ph. D. Dissertation, University of Southhampton.

Koker, M., & Thier, H. (1994). *Learning about environmental health risks: An evaluation study of the SEPUP Investigating Environmental Health Risks module* . Berkeley, CA: Science Education for Public Understanding Program.

Kolodner, J. L., Crismond, D., Gray, J., Holbrook, J., & Puntembekar, S. (1998). *Learning by design from theory to practice.* Paper presented at the Third International Conference of the Learning Sciences, Atlanta, GA.

Krajcik, J., Blumenfeld, P. C., Marx, R. W., Bass, K. M., Fredricks, J., & Soloway, E. (1998). Inquiry in project-based science classrooms: Initial attempts by middle school students. *The Journal of the Learning Sciences, 7*(3 & 4), 313-350.

Krajcik, J., & Layman, J. (1993, March, 1993). Microcomputer-based laboratories in the science classroom. *Research Matters to the Science Teacher, 31*.

Lemke, C., & Coughlin, E. (1998). *Technology in American schools: Seven dimensions for gauging progress* . Santa Monica, CA: Milken Family Foundation.

Linn, M. C., diSessa, A., Pea, R. D., & Songer, N. B. (1994). Can research on science learning and instruction inform standards for science education? *Journal of Research in Science Teaching, 31*(3).

Linn, M. C., & Hsi, S. (2000). *Computers, Teachers, Peers: Science Learning Partners*. Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., Shear, L., Bell, P., & Slotta, J. D. (1999). Organizing principles for science education partnerships: Case studies of students' learning about "rats in space" and "deformed frogs". *Educational Technology Research and Development, 47*(2), 61-85.

Loh, B., Reiser, B. J., Radinsky, J., Edelson, D. C., Gomez, L. M., & Marshall, S. (in press). Developing reflective inquiry practices: A case study of software, the teacher, and students. In K. Crowley, C. Schunn, & T. Okada (Eds.), *Designing for science: Implications from everyday, classroom, and professional settings* . Mahwah, NJ: Erlbaum.

Mandinach, E. B., & Cline, H. F. (1994). Modeling and simulation in the secondary school curriculum: The impact on teachers. *Interactive Learning Environments, 3*, 271-289.

Means, B., Coleman, E., Lewis, A., Quellmalz, E., Marder, C., & Valdes, K. (1997). *GLOBE Year 2 Evaluation: Implementation and Progress* . Menlo Park, CA: SRI International.

Means, B., Middleton, T., Lewis, A., Quellmalz, E., & Valdes, K. (1996). *GLOBE Year 1 Evaluation: Findings* . Menlo Park, CA: SRI International.

Mokros, J. R., & Tinker, R. F. (1987). The impact of micro-computer based labs on children's ability to interpret graphs. *Journal of Research in Science Teaching, 24*(4), 369-383.

Monaghan, J., Slotta, J. D., & Cuthbert, A. (1999). *A professional development model for effective Internet use: The Web-based Integrated Science Environment (WISE).* Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Boston, MA.

NRC. (1996). *National science education standards*. Washington, DC: National Research Council.

O'Sullivan, C. Y., Reese, C. M., & Mazzeo, J. (1997). *NAEP 1996 Science Report Card for the Nation and the States* . Washington, DC: National Center for Education Statistics.

Otero, V. K., Johnson, A., & Goldberg, F. (in press). How does the computer facilitate the development of physics knowledge by prospective elementary teachers? *Journal of Education*.

Petrovic, C., & Lavity, H. (1998). Coral Kingdom. *Reef Encounter: Newsletter of the International Association for Reef Studies, 23*.

Pizzini, E. L., Shepardson, D. P., & Abell, S. K. (1992). The questioning level of select middle school science textbooks. *School Science and Mathematics, 92*(2), 74-79.

Repenning, A., Ioannidou, A., & Phillips, J. (1999). Collaborative use and design of interactive simulations. In C. Hoadley (Ed.), *Proceedings of CSCL 1999* . Stanford, CA.

Resnick, M. (1996). Beyond the centralized mindset. *The Journal of the Learning Sciences, 5*, 1-22.

Resnick, M., Berg, R., & Eisenberg, M. (2000). Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. *Journal of the Learning Sciences, 9*(1), 7-30.

Ruben, B. (1994). Cyber-Ed. *Environmental Action, 26*(1), 24-27.

Samson, S., & Wilson, M. (1996). *The SEPUP Issues, Evidence and You curriculum: Achievement and student attitude evidence from the pilot year.* Paper presented at the Annual Conference of the American Educational Research Association, New York.

Schank, P., Coleman, E., Kozma, R., & Coppola, B. (1999). ChemSense: A learning environment for promoting representational competence and scaffolded collaborative investigations in chemistry. In C. Hoadley (Ed.), *Proceedings of the Computer Supported Collaborative Learning Conference* . Palo Alto, CA.

Schmidt, W. H., McKnight, C. C., & Raizen, S. A. (1997). *A splintered vision : An investigation of U.S. science and mathematics education*. Dordrecht ; Boston: Kluwer Academic Publishers.

Slotta, J., & Linn, M. C. (2000). How do students make sense of Internet resources in the science classroom? In M. J. Jacobson & R. Kozma (Eds.), *Learning the Sciences of the 21st Century* . Hillsdale, NJ: Lawrence Erlbaum & Associates.

Slotta, J. D., Chi, M. T. H., & Joram, E. (1995). Assessing the ontological nature of conceptual physics: A contrast of experts and novices. *Cognition and Instruction*.

Songer, N. B. (1996). Exploring learning opportunities in coordinated network-enhanced classrooms: A case of kids as global scientists. *The Journal of the Learning Sciences, 5*, 297-327.

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics* . Princeton, NJ: Educational Testing Service.

White, B. Y. (1993). Intermediate causal models: A missing link for successful science education? In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 4, pp. 177-251). Hillsdale, NJ: Lawrence Erlbaum Associates.

Young, V. M., Haertel, G., Ringstaff, C., & Means, B. (1998). *Evaluating Global Lab curriculum: Impacts and issues of implementing a project-based science curriculum* . Menlo Park, CA: SRI International.

Appendix: Lists for Searching the World Wide Web

On the Internet, there is no shortage of lists of technology-based science curricula. These lists range from the lightly edited education categories of Yahoo to more narrowly defined subject-matter interest lists. While the lists themselves are not authentic, inquiry-based science curricula, they may point to programs, curricula, or technology that teachers may find useful for enhancing the quality of learning in the science classroom.

We include the following "list of lists" to give teachers a way to search for additional science curricula using the World Wide Web. Note that many of these sites are better suited to curriculum developers than to individual teachers. Should teachers choose to use these resources, a few caveats are in order.

First, we cannot vouch for the selection criteria used at any of these sites. The programs we have reviewed and recommended in this document have been evaluated based on a particular set of criteria, which we set forth at the beginning of this document. Not all of these sites provide such criteria, so it is not always possible to know whether a particular site's review policies are consistent with a particular teacher's beliefs about teaching and learning.

Second, as with most material on the Internet, we cannot guarantee that all of these sites will be maintained and updated on a regular basis.

Finally, we encourage teachers who do choose to search for science curricula online to be active, informed consumers. The criteria described in this review provide useful metrics for evaluating technology-rich curricula, and we encourage teachers to adopt and refine these metrics as they continually assess and adapt authentic, technology-based science curricula for their classrooms.

CERES Astronomy Education Website

Web site: http://btc.montana.edu/ceres/

The Center for Educational Resources (CERES) offers six high school astronomy activities. Funded by NASA, CERES involves faculty at Montana State University and classroom teachers from across the nation. A team of master teachers, university faculty, and NASA researchers has created a series of web-based astronomy lessons for the CERES Project. These classroom-ready activities emphasize strategies from the National Science Education Standards (NRC, 1996). In addition to the six high school astronomy activities, CERES has an extensive library of on-line and interactive K-8 science education materials and two graduate level distance learning courses. Closely aligned with the NRC National Science Education Standards, these Web-based lessons make maximum use of on-line NASA resources, data, and images. Two types of classroom-ready lessons are available on-line:

- Student inquiries/Extension lessons. Students explore NASA data to construct first-hand knowledge about the astronomical universe. These internet-based lessons require one to four class hours and are tied explicitly to the NRC National Science Education Standards astronomy objectives. They can be used as an introduction to astronomy topics, as an intermediate activity, or as an extension activity that requires active participation by students.
- Spacequests. Classes divide into research teams to attack scientific problems. These collaborative group projects require four to ten class hours and integrate themes and unifying concepts in science with astronomy objectives from the NRC National Science Education Standards.

Explorer

Web site: http://explorer.scrtec.org/explorer/

The Explorer™ is a collection of educational resources such as instructional software, lab activities, lesson plans, and student-created materials for K-12 mathematics and science education. This collection of materials is organized by major topic in the curriculum and can be searched. Materials include everything from lesson plans to virtual field trips. There are about 300 items designed for high schools, about 75 of which are laboratories, field trips, or CD-ROM-based activities. The Explorer is being developed jointly by the Great Lakes Collaborative and the University of Kansas' UNITE group to involve educators and students in creating and using multimedia resources for active learning and "on time" delivery. To be included in the site, materials have to be approved by volunteer reviewers. Educators can join the site as contributors, reviewers, and users. Reviews are available, and many items can be downloaded.

Microsoft Anytime, Anywhere Learning

Web site: http://www.microsoft.com/education/aal/default.asp

Microsoft Corporation has developed an extensive approach to supporting teachers with software and hardware. Beyond their basic operating system and office software, Microsoft provides an educational network of curriculum, as well as a vision for laptop computing the company calls "Anytime, Anywhere Learning."

Microsoft Encarta Lesson Collection

Web site: http://encarta.msn.com/schoolhouse/default.asp

Many teachers and other authors have contributed curriculum to a compendium of activities called "Microsoft Encarta Lesson Collection." Teachers can access these activities individually by searching through the collection, and are not required to adopt the broad program of Anytime, Anywhere Learning. The activities in the Encarta Encyclopedia are designed to help students gain research and critical-thinking skills. Each activity helps students formulate questions, and then guides the student in using Microsoft Encarta Encyclopedia, as well as other resources to help find answers to those questions. In some activities, students may also find they need to conduct independent or collaborative research, perform analysis, and report on their findings to peers. The activities cover a wide range of ages and are appropriate for use with individual students or with cooperative learning groups.

National Science Teachers Association: Collection CD ROMs

Web site: http:// www.nsta.org/pubs/special/popular.asp

NSTA has published a broad library of CD-ROM and text-based activities for all science topics and grade levels. For example, "Views of the Solar System" provides a collection of images, animations, facts, and historical perspectives about the planets, moons, sun, and other parts of our solar system. Students can take a virtual flight over Martian volcanoes, descend into the sun, and experience the first moon landing. This activity includes a special section for educators, with an extensive resources list, NASA-developed activities, and NSTA journal articles that cover key processes in space science.